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HUMAN ENGINEERING PROCEDURES GUIDE

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
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Human Engineering (HE) procedures during the system acquisition process are presented for the assistance of various Air Force and industry personnel. The guide is divided into three parts. The first part of the guide is introductory material which scopes the effort and defines HE and human factors engineering (HFE). The second part provides guidance to Air Force and industry management. The third, and last, part is the largest section and it provides assistance to both Air Force and industry persons assigned direct responsibility for HE.

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The management portion ~~(Section 2.0)~~ shows current management aspects of the HE process utilizing directives, specifications, regulations, and pamphlets. HE activities are described in general terms of both what should be done and when it should be accomplished. The practical value of HE is discussed in the management section. Various HE program management relationships are suggested also, and the procedure for including HE in the total system effort is presented.

The user's portion ~~(Section 3.0)~~ provides assistance in the areas of HE documentation and requirements that should apply to the program. Program analysis source data suggestions are provided. The planning and scheduling of HE activities are discussed. The required coordination between HE and other disciplines are presented along with the need for coordination with management. Other topics presented include: possible allocation of effort to consultants and/or subcontractors, preparation of the HE portion of the RFP, contractor proposal preparation, proposal evaluation, contractor task acomplishment, and contractor task monitoring.

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ERRATA

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
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SUMMARY

This guide is divided into three parts. The first part is introductory material which scopes the effort and defines human engineering and human factors engineering. The second part is designed to be used by Air Force Program Element Managers, System Program Offices, and contractor Program Managers. It is intended to show the current management aspects of the human engineering process utilizing directives, specifications, regulations, and pamphlets. Human engineering (HE) activities are described in general terms of both what should be done and when it should be accomplished. The practical value of HE is discussed in the manager's section. Various HE program management relationships are suggested also, and the procedure for including HE in the total system effort is presented.

The third section is provided to assist both the Air Force HE personnel and the contractor HE manager and user personnel. For the HE managers or users who have had considerable experience, it may be used for a review or checklist to be sure that they are doing all of the tasks that they should. For users who are new to this type of work, most of what is provided will be useful to accomplish their required tasks. Assistance is provided in the following areas:

- a) Human engineering, documentation and requirements that should apply to the program.
- b) Source data to find out what HE effort is needed.
- c) Necessary planning and scheduling to accomplish the program.
- d) Necessary coordination between HE and other disciplines and with the contractor program manager as well.
- e) Possible allocation of effort to consultants and/or subcontractors.

f) Preparation of HE portion of the request for proposal.

g) Contractor proposal preparation.

h) Proposal evaluation.

i) Contractor task accomplishment.

j) Air Force monitoring of contractor.

It is intended that this guide be of assistance to both Air Force and industry management to understand and utilize HE. It is further intended that the guide be of help to the relatively inexperienced Air Force or industry person assigned responsibility for HE in the system acquisition process.

DoD contractors, government activities and other users of this document are invited to submit comments and suggestions for improvement to AFAMRL/HED, Wright-Patterson AFB OH 45433.

PREFACE

This guide is the result of work conducted under Air Force Aerospace Medical Research Laboratory Contract No. F33615-79-C-0520 between 2 April 1979 and 2 December 1979. The AFAMRL technical contract monitor was Mr. Jean ~~M. Ring~~ and, within the Boeing Aerospace Company, the program was directed by Mr. W. J. Hebenstreit of the Engineering Technology Crew Systems and Simulation Technology organization. The author is indebted to their guidance and contributions as well as the help of numerous persons in the Crew Systems and Simulation Technology organization.

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DEFINITIONS/ACRONYMS

A/C	Aircraft
ADC	Armament Development Center
AEDC	Arnold Engineering Development Center
AFAMRL	Air Force Aerospace Medical Research Laboratory
AFETR	Air Force Eastern Test Range
AFFTC	Air Force Flight Test Center
AFHRL	Air Force Human Resources Laboratory
AFR	Air Force Regulation
AFSC	Air Force Systems Command
AMD	Aerospace Medical Division
AMRL	Aerospace Medical Research Laboratory
ASD	Aeronautical Systems Division
ASMS	Advanced Surface Missile System
AWACS	Airborne Warning and Control System
CAD	Computer-Aided Crewstation Design Model
CAFES	Computer-Aided Function Allocation and Evaluation System
CAPE	Computer Accommodated Percentage Evaluation
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CGE	Crew Station Geometry Evaluation Model
COMBIMAN	Computerized Biomechanical Man-Model
DI	Data Item
DMS	Data Management System
DSARC	Defense System Acquisition Review Council
DT&E	Development Test and Evaluation
ECP	Engineering Change Proposal
EEG	Electroencephalograph
EKG	Electrocardiograph
ERP	Eye Reference Point
ESD	Electronics System Division

DEFINITIONS/ACRONYMS (cont.)

FAM	Function Allocation Model
FPC	Flow Process Chart
FSD	Full-Scale Development
FSD	Functional Sequence Diagram
FSED	Full-Scale Engineering Development
GSR	Galvanic Skin Response
HE	Human Engineering
HECAD	Human Engineering Computer Aided Design
HED	Human Engineering Division, Crew Station Integration Branch
HEDGE	Human Engineering Data Guide for Evaluation
HFE	Human Factors Engineering
HFTEMAN	Human Factors Test and Evaluation Manual
HQ	Headquarters
ICD	Interface Control Drawing
ILS	Integrated Logistics Support
ISD	Instructional System Development
JANAIR	Joint Army Navy Aircraft Instrumentation Research
LCC	Life Cycle Cost
MENS	Mission Element Need Statement
OPR	Office of Primary Responsibility
OSD	Office of Secretary of Defense
OSD	Operational Sequence Diagram
OT&E	Operational Test and Evaluation

DEFINITIONS/ACRONYMS (cont.)

PDR	Preliminary Design Review
PMD	Program Management Directive
PMP	Program Management Plan
PO	Program Office
R&D	Research and Development
RFP	Request for Proposal
ROC	Required Operational Capability
SAINT	Systems Analysis of Integrated Networks of Tasks
SAMSO	Space and Missile Systems Office (BMO)
SON	Statement of Operational Need
SOSD	Spatial Operational Sequence Diagram
SOW	Statement of Work
SPO	System Program Office
SRP	Seat Reference Point
TLA-1	Timeline Analysis Program - Mode One
T&E	Test and Evaluation
T.O.	Technical Order
VPX	Advanced Patrol Aircraft
WAM	Workload Assessment Model
WBS	Work Breakdown Structure

1.0 INTRODUCTION

1.1 Purpose of Guide

The objective of this guide is to provide assistance to human engineers and managers in the planning, scheduling, and performance of HE (Human Engineering) in the system/equipment acquisition process. There has been a long-standing need to assist the relatively inexperienced Air Force or industry person assigned responsibility for HE in the multiphase system acquisition process. There has also been a need to help management in both Air Force and industry to understand and utilize HE in the system acquisition process.

Occasionally, the relatively inexperienced person assigned responsibility for Human Engineering starts an inappropriate Human Engineering effort with requirements for data which may never be used. Human Engineering must be considered, along with all other disciplines, for the contribution it can make to the system/equipment acquisition, with each requirement justified, and all unnecessary requirements tailored out.

Within the AF, or other services, there has been no recent documentation which completely describes all Human Engineering tasks which should take place during a major system acquisition program (Ref. 2, AFSCP 800-3)*. There has been no common or unified approach as to what Human Engineering is or how it relates to other areas concerning the human or other disciplines. It is the purpose of this guide to provide a better understanding and appreciation of Human Engineering to help both managers and the people assigned Human Engineering responsibility in the system/equipment acquisition process in the Air Force and in industry.

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*Ref 2, AFSCP 800-3 defines major program as "A program so designated by OSD normally having an estimated cost of $50 million in RDT&E or $200 million in production."

1.2 Scope of Guide

This document is organized into three sections. This section, 1.0 Introduction, is intended for use with both Sections 2.0 and 3.0. Section 2.0, HE significance for Acquisition Manager, is intended to be used by both Air Force and contractor managers to show current management aspects of the HE process. Section 2.0 may be used independently from 3.0; however, Section 3.0 is dependent on data in both 1.0 and 2.0. Section 3.0, HE Application During System Acquisition, is intended to present and develop HE procedures throughout the major system acquisition process (Ref 3, OMB Circular A-109). Section 3.0 is intended for use by Air Force or industry personnel directly assigned to the HE function. These include both HE managers and analysts. The total guide is directly applicable to HE alone rather than the total field of HFE, Human Factors Engineering, (see definitions in following section). However, it is the intent of the guide to present the relationship of HE to the other HFE elements: Biomedical, Manpower and Personnel Requirements, Training, and Human Factors Test and Evaluation (T&E). Although the other HFE elements are necessary to the successful accomplishment of the acquisition process, the procedures for the accomplishment of Manpower and Personnel Requirements and Training are not included in this guide. The relationship of HE to other HFE elements and to other disciplines or technologies such as Maintainability, Safety, Reliability, and Survivability, are indicated in all three sections of the guide.

1.3 Human Engineering and Human Factors Engineering

MIL-STD-721B (Ref. 61) defines Human Engineering as "The area of human factors which applies scientific knowledge to the design of items to achieve effective man-machine integration and utilization." In the Air Force, Human Engineering is defined in Air Force Regulation (AFR) 800-15 as "the application of knowledge about human capabilities and limitations to the system or equipment design, to achieve desired system performance requirements through the most effective use of man's performance capability.

Human Engineering is one of five elements in the Human Factors Engineering and Management area of system acquisition. The other elements are: Biomedical; Manpower and Personnel Requirements; Training; and the Human Factors Test and Evaluation Element.

Human Factors Engineering in the Air Force is a management concept to ensure the incorporation of its five elements into the mainstream engineering and program management effort of all acquisition programs and conceptual studies. As such, Human Factors Engineering is a much broader term than Human Engineering. However, whenever the term Human Factors Engineering is used, it includes Human Engineering. Again, Human Engineering is concerned with the design and development of the system or equipment for the best utilization of human capabilities and limitations in the operation, control, maintenance, or support of the system. "The Biomedical Element includes every area that requires provisions for the promotion of health and safety -- and for the protection, sustenance, escape, survival and recovery of personnel employed within the total system environment."*

There is some overlap with Human Engineering in the design area. The Manpower and Personnel Requirements "element includes the development of manpower and personnel requirements to insure that enough trained people are available to operate, maintain, control, and support the system or equipment". The Training "element includes all training provided, conducted, or managed by the using command, ATC, or the contractor. It incorporates, as a minimum, the trained personnel requirements, training plan, training equipment development, training, training support data, and training facilities." This element is based on the output of the Manpower and Personnel Requirements element. The Human Factors Test and Evaluation Element "is part of the system test effort and will be conducted as directed in AFR 80-14. It is concerned with determining whether Air Force personnel, with system training, can in fact operate, maintain, and support the system in its intended operational environment."

*All quotes in this section are from AFR 800-15.

2.0 HE SIGNIFICANCE FOR ACQUISITION MANAGERS

This section is prepared for Air Force Program Element Managers (Ref. 2, AFSCP 800-3), System Program Office Managers (Ref AFSCP 800-3), and contractor Program Managers. It should be of use to them as a guide for what they need to understand about HE. Another major section of this guide describes the details associated with the several HE activities.

Data summarizing HE requirements as contained in applicable directives, regulations, and specifications are included in this section. HE activities are described in general terms of both what should be done and when it should be accomplished. The practical value of HE is discussed. Various HE program management relationships are suggested and the procedure for including HE in the total system effort is presented.

2.1 Documented Requirements

The specification of HE requirements is critical to the successful accomplishment of any major program effort. These requirements are both of a directed and practical nature. Paragraph 2.3 (HE Value) presents many of the practical HE requirements along with their value. This paragraph presents the documented HE requirements including their origins. These requirements are presented both for the Air Force and the contractor; however, the particular requirements which direct the Air Force are more general and slightly different from the more detailed contractor requirements. The contractor's requirements are derived from Air Force requirements.

2.1.1 Documented Air Force Requirements

These requirements (see Table 2.1-1) derive from Department of Defense Directive 5000.1, Subject: Major System Acquisitions (Ref. 8). This directive states that "the number and skill levels of personnel required and human engineering factors shall be included as constraints in system design. The integration of the human element and system shall start with initial concept studies and be refined as the system program progresses to form the basis for personnel selection and training, training devices, simulators and planning related to human factors".

Table 3.0-1. Document Applicability to Human Engineering

Requirements review documents	HE Aspects	General requirements	Coordination functions	Level of effort	Schedule	Source data	Applications	Methodology techniques	Analysis	Design	Test and evaluation	Other
OMB Circular A-109		●										
Department of Defense Directives												
5000.1	Major System Acquisitions	X			●							
5000.2	Major System Acquisitions Process				●							
5000.3	Test and Evaluation										X	
Air Force Regulations												
80-14	Test and Evaluation		●		X						X	
800-2	Program Management				●							
800-3	Engineering for Defense Systems	X	●		●							
800-8	ILS Program for Systems and Equipment		●									
800-12	Acquisition of Support Equipment	●										
800-15	(and supplement 1) Human Factors Engineering and Management	X	X								X	
Military Standards												
MIL-STD-454	Standard General Requirements for Electronic Equipment	X										
MIL-STD-499	Engineering Management		●		●	●			X			
MIL-STD-882	System Safety Program for Systems . . .	●	●									
MIL-STD-1472	HE Design Criteria . . .	X							●	X	X	
MIL-STD-1388	Logistics Support Analysis	●	●				X		X			
MIL-STD-411	Aircrew Station Signals									X		
Military Specifications												
MIL-H-46855	HE Requirements for Military Systems	X	X	●			X	X	X	X	X	X
MIL-L-25467	Lighting, Integral Aircraft Instrument . . .									X		
H-series Data Items		X	X	X	X	X	X	X	X	X	X	X
AFM 50-2 Instructional Systems Development		X										
AFP 50-58 Handbook for Designers of Instructional Systems							●		X			
AFP 800-7 Integrated Logistics Support			●			X	X					
AFSCP 80-5 Guide for Advanced Development		X	●		●							
AFSCP 800-3 A Guide for Program Management		X	●		●						X	
Human Engineering Guide to Equipment Design		X						X	X	X	X	X
DH1-3 Human Factors Engineering		X	X				X	X	X	X	X	X

X Primary applicability ● Secondary applicability

In accordance with AFR 800-3, Engineering for Defense Systems, HE is included as a significant part of the program engineering tasks. HE as an element of HFE is required as a part of the engineering effort throughout the system life cycle. It uses data from, and contributes to, the system engineering process in developing specification requirements.

AF Regulation 800-15, Human Factors Engineering and Management, establishes the total system HE effort. It is applicable throughout the system life cycle. AFR 800-15, Paragraph 2 on policy states "HFE must be an integral part of the R&D planning, conceptual study efforts, exploratory, advanced, and engineering development projects, equipment procurements, modifications, and system acquisition programs where the intended end product has human performance as a integral part".

Attachment 1 to AFR 800-15 (including AFSC Supplement 1) further indicates that AFSC shall establish a command office of primary responsibility (OPR; Ref. 2, AFSCP 800-3) for HFE and require the proper subordinate echelons to designate their OPR for HFE. The PO's (program offices; Ref. AFSC 800-3) will insure that appropriate HFE effort is planned for and implemented in all systems and equipment programs within the resources allotted to the program. A part- or full-time HFE manager will be assigned upon formulation of the program office cadre.

The AFSC product divisions, Space Division (SD), Ballistic Missile Office (BMO), Electronic Systems Division (ESD), Aeronautical Systems Division (ASD), and the Armament Division (AD) will assign trained HFE managers to manage and conduct the HFE effort on systems or equipment with substantial or critical man-machine interface elements. Military Specification MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment and Facilities (Ref 4) establishes and defines the requirements for applying human engineering to the development and acquisition of military systems, equipment and facilities.

These requirements include the work to be accomplished by the contractor, or subcontractors in conducting a human engineering effort integrated with the total system engineering and development effort. It is not intended that all the requirements in MIL-H-46855 should be applied to every program or program phase. It must be applied judiciously and tailored to fit the program or program phase and the acquisition strategy to achieve cost effective acquisition and life cycle ownership of defense material.

The associated data requirements are found in DoD 5000.19-L, Acquisition Management Systems and Data Requirements Control List, Data Item Descriptions (DIDs, Form 1665), DI-H-7051 through DI-H-7059 (Ref. 62). These data items should also be tailored and justified based on the phase of system acquisition and the acquisition strategy as approved by the system program manager.

Military Standard MIL-STD-1472 Human Engineering Design Criteria for Military Systems, Equipment and Facilities (Ref 9) is a set of human engineering design criteria, principles and practices to achieve mission success through integration of the human into the system, subsystem, equipment, and facility, and achieve effectiveness, simplicity, efficiency, reliability, and safety of system operation, training, and maintenance.

The specification, the data items, and the standards are Tri-Service and Industry coordinated and approved by DoD. The appendix to MIL-H-46855 is a guide for tailoring the specification.

2.1.2 Documented Contractor Requirements

Contractor requirements are provided directly by the contract statement of work. Generally, MIL-H-46855 and MIL-STD-1472 are specified contractual documents, to which the contractor must adhere. The contract data requirements list (CDRL: DD Form 1423) would contain any data items associated with MIL-H-46855 and for which the Air Force wanted data. CDRL

items typically include the HE Program Plan, test plan, system analysis report, and/or progress report. In addition to the documented requirements, the contractor should be motivated to capitalize on Human Engineering to help design and develop the most efficient, effective, and safe system possible within the cost and schedule imposed.

2.2 Human Engineering Support in System Acquisition

The Human Engineering effort includes participation in three primary areas of system development: analysis; design and development; and test and evaluation, (Ref 4, MIL-H-46855). As a part of the design and development area, technical data procedures are often developed. All of these areas or activities are performed in combination with considerable inter- and intra-coordination. The coordination includes planning and scheduling of these basic efforts to insure that the proper source data are available to do the necessary work, the proper work is performed at the proper time, and that the results of the work are provided to the proper persons. Frequently, as a result of the work performed, an interactive effort is made to refine the Human Engineering design requirements. For example, as a result of test and evaluation, more analysis and eventual redesign may be necessary. Typical interaction relationships between Human Engineering areas and other technology areas of system development are shown in Table 2.2-1.

As indicated in Paragraph 1.3, Human Engineering is one of five elements of Human Factors Engineering. Figure 2.2-1 illustrates this relationship.

2.2.1 Analysis Area

HE areas of work are like other technology areas or activities in that there are problems brought about by the new system acquisition and these problems are frequently solved by the analysis process of breaking them down into smaller and smaller elements to the point where they can be

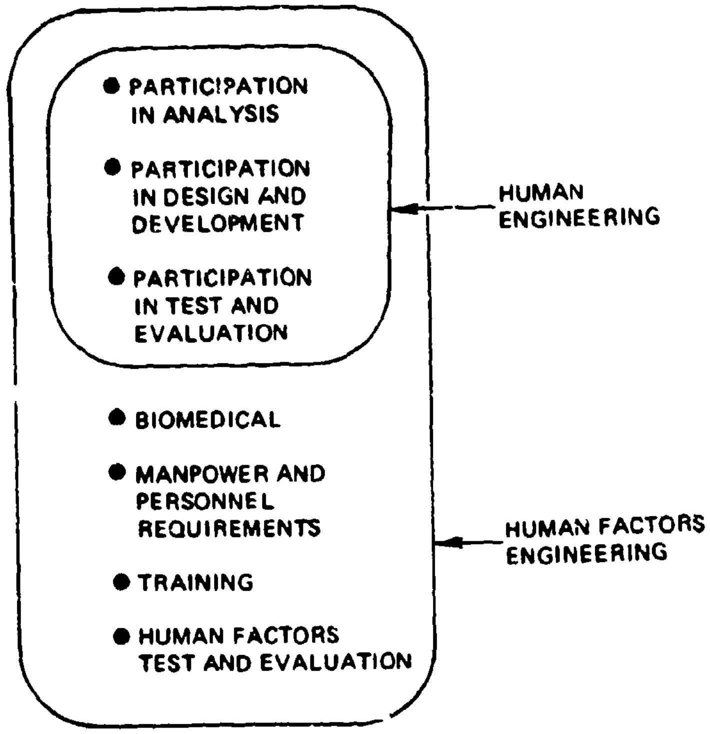


Figure 2.2-1. Human Engineering Relation To Human Factors Engineering

Table 2.2-1. Human Engineering Relationship to Other Technologies

	Interface Matrix / Technologies — Areas of system development (per MIL-H-46855)	Analysis	Detail Design	Procedures Development	Test and Evaluation
1	**Biomedical**		X	X	X
2	Personnel requirements	X	X		X
3	Training/ISD	X	X	X	X
4	Test and Evaluation	X	X	X	X
5	Publications	X		X	X
6	System Engineering	X			
7	Crew Station Design	X	X		X
8	Passenger Accommodations	X	X		X
9	Operations Analysis	X			
10	Communications	X	X		X
11	Propulsion		X		
12	Accessories		X		
13	Guidance and Control		X		
14	Avionics		X		
15	Reliability	X	X		X
16	Maintainability	X	X	X	X
17	Survivability/Vulnerability		X		
18	System Safety	X	X	X	X
19	Field Service/Logistics		X	X	X
20	Software	X	X	X	X
21	Life Cycle Costs	X	X		X
22	Support Equipment	X	X	X	X

handled. At the smaller element level, significant aspects of the total problem can be examined in detail. Answers to several detailed questions/problems are more easily obtained than answers to a few top level questions/problems.

Generally, the analysis process starts with the system mission as described by a baseline scenario. The mission objective and functions that must be performed by the system are identified, described, and sequenced. These functions are then analyzed to determine their proper allocation to personnel, software, or equipment. Once allocated, the personnel functions are further analyzed to determine the specific operator/maintainer tasks which must be performed to accomplish the functions. The tasks are further detailed to show estimated time and space relationships. Frequently, personnel performance reliability estimates are also provided. These analyses are performed by the use of several (Ref. Para. 3.9.4) manual (paper and pencil) and automatic (computer/software) techniques.

The results of these analyses are specific hardware design criteria. When applied, these design criteria will insure hardware compatibility with human performance capabilities and limitations. For example, human performance reliability data are used by System Safety to fully develop the system safety fault trees. Technical publications may be initiated based on the task analysis procedures data. Personnel manning and skill level documentation may be established based on the analyses data. Training data and equipment may be initiated from the analysis effort. Table 2.2-1 shows the several technologies from which HE analysis receive inputs or to which applications data are provided. In addition to those already indicated, System Engineering and Operations Analysis frequently provide data from which the HE effort may be initiated. Crew Station Design receives the results of HE workload analysis in order to determine proper flight or mission crew size. Figure 2.2-2 illustrates the time period during a major system acquisition in which the analysis and other areas of system development efforts may occur most usefully.

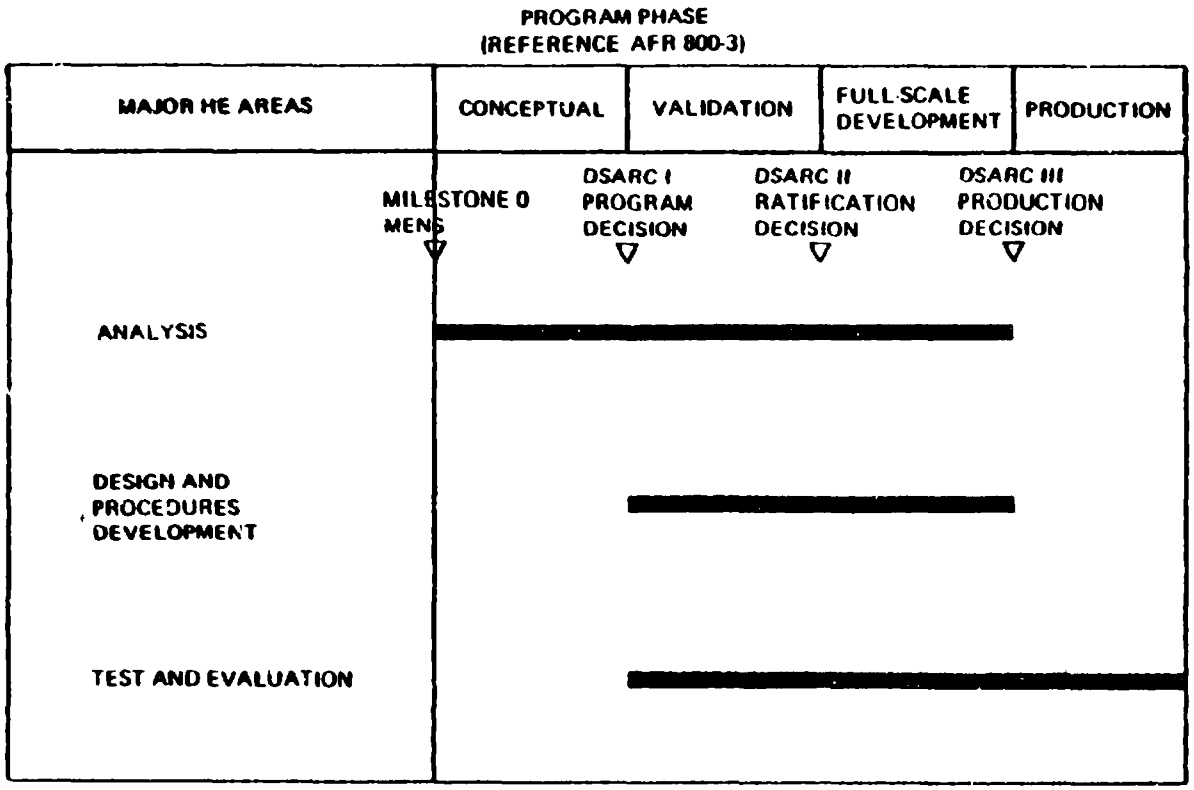


Figure 2.2-2. Applicable Program Stages for Human Engineering Areas of System Development

2.2.2 Design and Development Area

The purpose of this area of work is to provide the system man-machine design which incorporates all necessary human engineering design criteria. If the man-machine interface design activity is not provided directly by HE, then it is the job of HE to supply appropriate design data to the project design organization. The required HE sign-off on drawings indicates drawing compliance with appropriate HE design criteria. The man-machine interface design is not limited to portions of system equipment, but includes software design, procedures, work environments, and facilities associated with the system functions requiring personnel interaction.

This area of work is accomplished by converting the results of the analysis activity into HE and Biomedical design criteria. This work is heavily dependent on the selection of applicable MIL-STD-1472 (Human Engineering Design Criteria for Military Systems, Equipment and Facilities) design criteria. Several HE techniques and tools are used. These include the use of drawings, checklists, vision plots, reach envelopes, mockups, specifications, and various computer workstation modeling programs. The final developed design is a man-machine interface that will operate within human performance capabilities, meet system functional requirements, and accomplish mission objectives.

There are several disciplines that HE interfaces with during the detailed design effort (see Table 2.2-1). System Engineering and maintainability are two of the most important of these. In fact, Human Engineering should be a part of system engineering. Most maintainability design criteria are, in fact, Human Engineering design criteria. The most appropriate time during a major system acquisition program in which the HE design effort may usefully occur is shown in Figure 2.2-2.

2.2.3 Test and Evaluation Area

The HE test and evaluation (T&E) effort is important to verify that the man-machine interface portion is properly designed so that the system can be operated, maintained, supported and controlled by user personnel in its intended operational environment. HE personnel must work closely with operational, maintenance, system engineering, logistics, and training personnel during operational T&E. HE T&E also provides HE performance data and design criteria for use in the development of later, follow on system acquisitions or modifications.

There are approximately 20 well known tools and techniques used to perform HE T&E. These include test observation, checklists, worksheets, environmental measurement, system records review, interviews, questionnaires, sound and video tapes, photography, event recording, physiological measure- ment, simulation, and statistics. Figure 2.2-2 illustrates the proper time in which the HE T&E effort may usefully occur during a major system acquisition.

2.3 HE Value

There are two ways to prove the value of a sound HE effort. One is to show positive results of HE activities, and the other is to show the negative results from the lack of HE. The following material examines the values of the HE effort from both viewpoints.

2.3.1 Benefit from HE

As with most worthwhile efforts, it takes an investment of money and time to gain eventual savings, increased performance, safety, and user satisfaction. The investment in HE is relatively small compared to other areas. The return on the investment is relatively high. The Air Force acquires a system which: (1) is designed to permit operator, control and maintenance personnel to achieve required performance; (2) minimizes skill

and personnel requirements and training time; (3) achieves required reliability of personnel-equipment combinations; and (4) emphasizes safe operations, maintenance, and control. Some of these benefits can be seen from Human Factors Tests and Evaluation Reports (Refs. 66, 67, 68, as typical). Some typical examples of problems found in various tests by Human Factors Engineering T&E people as reported by Crites (Ref. 63) are:

"a. Fastener problems - On the F-15 maintenance was seriously delayed because the door fasteners would freeze into the nut plates. As many as 20 in one door would have to be drilled out. Improper provisioning of tools, material incompatibility, and ineffective procedures contributed to this problem.

b. It took up to 8 hours to remove one cotter pin from the flaperon actuator of the F-16. This was an extreme case of poor accessibility.

c. The nosewheel landing gear door would close inadvertently up to 45 minutes after hydraulic pressure was applied. This created a serious hazard to those working around the aircraft. We prepared an on-site training video tape warning of the hazard, and all contractor and Air Force personnel were shown this hazard within 24 hours of its identification.

d. The A-10 pilots had to lower their heads nearly 10 inches in order to use the gunsight after high drag bomb delivery.

e. Ejection Seat Failure to Deploy - The pilot of an A-7 reported that he had pulled the ejection handle but the seat failed to fire. Since we had the same ejection seat in the F-15, we wondered if an incorrect maintenance procedure could have accounted for the failure. The ejection seat personnel did identify a design deficiency that would allow a maintenance man to misrig the cable to the initiator. We made a video tape of a seat being misrigged and sent copies to the F-15 System Program Office (SPO), prime contractor, seat contractor, and Life Support SPO. Design changes were implemented to correct this deficiency."

The ultimate test of value is how well the system performed its mission. If the human operator, maintainer, or controller can perform his job efficiently, effectively, and safely, the system has been well human engineered. If there are errors or accidents due to the human element, perhaps the system was not well human engineered.

Although HE cannot take sole credit, flying safety statistics have improved greatly within the past 20 years. This is because of the concerted application of HE principles to cockpit design, as well as other areas of aircraft operations and maintenance. Operator performance has been shown to improve to the point of significantly affecting overall system performance. The difference between a well-designed, versus a poorly-designed, console layout may be an increase in overall operator reliability by an order of magnitude. The time required to perform complex tasks may easily be cut in half by the application of proven HE design criteria.

2.3.2 Problems from Lack of HE

Until recently, it has been difficult to obtain detailed data directly related to problems resulting from the lack of HE. However, many of the problems found during T&E (see previous paragraph) are evidence of the lack of a good HE effort during the design and development phase. Some of the problems are resolvable, but it costs more to do so during this phase. Problems found during the operational phase are still more costly to resolve. Sometimes problems are identified only after a crucial happening such as a recent (1979) F-16 accident after an aerial refueling as reported by Griffiths in Aviation Week and Space Technology. "Also the aerial refueling door was open at the crash site. An Air Force official said closing the door after refueling is the pilot's responsibility" (Ref. 64). This is not to imply that the pilot was in any way responsible for the accident, but to show that the system was designed such as to increase the probability that the pilot would make an error. Accident reports showing pilot error as a direct or contributing cause of an accident need careful study to determine if the design increases the probability of pilot errors and to modify the design in such cases.

A non-Air Force incident receiving national attention is worthy of mention because it shows the lack of HE; it is so costly, and it has affected so many people. This is the Three Mile Island Nuclear Power Plant problem. It has provided pressure to bolster a HE effort in the nuclear power industry. The accident investigation findings (Ref. 10, NUREG-0560) state that "Human factors engineering has not been sufficiently emphasized in the design and layout of the control rooms. The location of instruments and controls in many power plants often increases the likelihood of operator error, or, at the least, impedes the operator in efficiently carrying out the normal, abnormal, and emergency actions required of him". With this disregard for HE principles, it was inevitable that the accident should have occurred. It is, of course, difficult to obtain data as to the cost in total dollars, time, and effort lost because of this accident, but it is not hard to imagine the small percentage cost of a reasonably sound HE effort in comparison. The temptation is always present to avoid this small percentage cost, and to hope that power plant design engineers have sufficient skill to incorporate all necessary HE design features. However, proper knowledge of HE principles and criteria is too much to expect without HE training. Typical HE design criteria violations which have occurred in power plant control room design are as follows:

a. Instrumentation and controls are located beyond the operator's normal duty station and visual envelope; in some cases, operators' backs are positioned towards the displays which they must monitor.

b. Displays are located to allow erroneous readings due to parallax.

c. Displays and controls are mislabeled according to their function.

d. Displays and controls are arbitrarily located without functional grouping.

e. Panel layouts for similar systems are designed as mirror images of each other, thereby violating HE principles of transfer of training.

f. Annunciator audible warning systems are misused to the point of serving more to rattle the operator and overload his sensory mechanisms than to focus his attention on the specific problem at hand.

Similar design deficiencies have been found in Air Force Systems --- missile systems, space systems, command and control systems, aircraft systems, and support equipment.

2.4 HE Program Management

Whereas there is little doubt or interpretation as to what basic HE activities must be performed by the Air Force and the contractor during a major system acquisition, there is considerable latitude allowable as to the organizational relationships and management of the contractor HE effort. A survey of present day practice indicates a variety of methods in which the HE organization can be established within the contractor program organization. (Ref. 11, Geer 1976). Whatever the organization, Air Force or contractor, the important factors are the urgent need for HE to be able to communicate vertically to its management and laterally to the other technologies or program groups which serve its needs and which it, in turn, serves. Both the Air Force and contractor HE programs should be coordinated with system engineering, maintainability, system safety, reliability, survivability/vulnerability, integrated logistics support, and other HFE functions including biomedical, personnel, and training.

2.4.1 HE in Air Force Organization

In accordance with AFR 800-15, AFSC maintains a command office of primary responsibility (OPR) for HFE and requires subordinate echelons to do the same. Specifically, Space Division (SD), Ballistic Missile Office (BMO), Aeronautical Systems Division (ASD), Armanent Division (AD), Arnold

Engineering Development Center (AEDC), Air Force Flight Test Center (AFFTC), and Air Force Eastern Test Range (AFETR) have established HFE focal points which perform and coordinate various HFE activities for the various field command programs. Specific program offices ensure that the appropriate HFE effort is planned for and implemented in all systems with a significant man-machine interface. A part- or full-time HFE manager should be assigned upon establishment of the program office organization. It is this HFE manager's job to manage, monitor, and conduct the program HFE effort. AMD and AFHRL also provide HFE personnel for consideration and prompt, effective support to program offices, other AFSC field command HFE staff officers, and R&D managers.

2.4.2 HE in Contractor Orgaization

The HE function is found in various places in various contractor organizations. The function is also described by a variety of organizational names. The two basic areas in which HE operates are in staff support technology groups and in program project design groups. Some of the names under which HE operates are Crew Systems, Ergonomics, Human Factors, Human Engineering, Engineering Psychology, Behavioral Sciences, Bioengineering, Biotechnology and Bioastronautics.

Several aerospace contractors do not have engineering staff organizations from which to obtain specialized technology skills such as HE. Their project organizations, including all project personnel exist within the company only for the purpose of the project. They are hired for that project alone and they are laid off or completely reassigned to a new organizational group when their function for that project is completed.

The specific relation of HE to other groups within a program project varies in accordance with the program RFP or the desires of the program manager. The RFP may indicate the desired relationship for HE by the organization of the SOW or the WBS (Work Breakdown Structure, Ref. 31). The Air Force may informally request the location of HE within the project. In any case, HE is typically included as a part of System Engineering, Product Assurance, Logistics Engineering, or Design Engineering (Ref. 5, AFR 800-3). Within System Engineering, it may be subsumed under Specialty Engineering or it may report directly to System Engineering. HE is found reporting directly to Project Engineering only on smaller programs, not major system acqusitions.

2.5 Initial Application of HE to Program

This section briefly describes the method by which HE is initially incorporated into the major system acquisition process. The acquisition process generally consists of five phases (Ref. 12, AFM 11-1), the first of which is the Conceptual Phase. The first major task to accomplish during this phase is the preparation of the SON (Statement of Operational Need) by HQ USAF or a major operating command. (Ref. 13, AFR 57-1). Mission analysis is performed by AFSC at the same time to support the SON preparation effort. The SON provides criteria for the developmental planning of a specific program and contains statements of an operational need arising from a described Air Force Mission. Since the SON serves as a basis for specific design planning, it is desirable that HE contribute to its preparation through providing advice on the kinds of HE requirements that can reasonably be made at this stage in development. After appropriate review of the SON by AFSC, HQ USAF prepares a PMD (Program Management Directive, Ref. 2, AFSCP 800-3). The PMD is used to direct and guide appropriate action in the Conceptual Phase. This includes the actions to be performed by the commands to translate the SON into a proposal for a new program.

It is at this point, the preparation of the PMD, that the HQ USAF Program Element Manager must insure that HFE (including HE) requirements are included. Although the content of the PMD is tailored to the needs of each individual program, any major system acquisition requires a significant man-machine interface which, in turn, requires the application of HFE requirements. In addition to being used to state HFE requirements, the PMD may be used to request special HE studies or analysis and assign responsibility to specific organizations.

The PMD requirement for HFE may be worded as follows:

> In compliance with AFR 800-15, AFSC will insure that the human component of the system can safely and effectively operate, maintain, support, and control the system in its intended operational environment.

The implementing command, usually AFSC, well then include HE in their Form 56, AFSC Program Directive (Ref. 2, AFSCP 800-3). It establishes the program priority and insures guidance and direction to the AFSC organizations' product divisions and Program Offices. The AFSC Form 56 may be used to call out the need for specific HE laboratory (e.g. AFAMRL HED) support. In establishing the PO (Program Office), AFSC must insure that qualified personnel are assigned the particular task of implementing the HE program requirements.

Frequently, the PMD is modified by program supplements at later points in the program schedule. If HE or HFE is not included originally as a program requirement, it may be included later.

One of the most important of many tasks that the PO must accomplish is the preparation and update of the PMP (Program Management Plan). This plan must include the organization and functions of the PO, in general, and the particular role of HFE within the PO. The PO establishes not just the HFE manager but the amount of HE effort to be performed on the program. The

Air Force manager will tailor the effort to suit the program needs and budget. Later in the acquisition cycle, the contractor(s) will prepare their own PMP as a part of the proposed program development effort. The contractor PMP must include HE and its organizational and functional relationship to the several related technologies such as listed in Table 2.2-1. In similar manner to the Air Force, the contractor program manager must insure that the HE management job is assigned and funded to satisfy Air Force contractual requirements.

3.0 HE APPLICATION DURING SYSTEM ACQUISITION

The purpose of this major section of the guide is to assist both the Air Force HE personnel and the contractor HE manager and user personnel. For the managers or users who have had considerable experience, it may be used for a review or checklist to be sure that they are doing all of the tasks that they should. For users who are new to this type of work, most of what is provided herein will be useful to accomplish their several tasks. New HE personnel will find that HE offers both variety and a challenge. In general, the workload is rigorous. It is the nature of HE to offer a seemingly unending quantity of problems and opportunities. The HE job is not like that of designing a landing gear; such tasks tend to have a definite time at which they may be considered complete. For HE there is really no point at which the job is totally finished. It is the task of the human engineering specialist to choose and work the tasks which are most significant to the program at any given point in the acquisition process. The following paragraphs provide assistance in system acquisition areas of:

a. Human engineering, documentation and requirements.
b. Source data to find out what HE effort is needed.
c. Planning and scheduling information.
d. Coordination between HE and other disciplines and with the contractor program manager.
e. Possible allocation of effort to consultants and/or subcontractors.
f. Preparation of HE portion of the request for proposal.
g. Contractor proposal preparation.
h. Proposal evaluation.
i. Contractor task accomplishment.
j. Air Force monitoring of contractor.

The above activities are depicted in typical sequential order in Figure 3.0-1. The Figure also shows which activities are performed by the Air Force and the contractor. The first five activities must be performed by

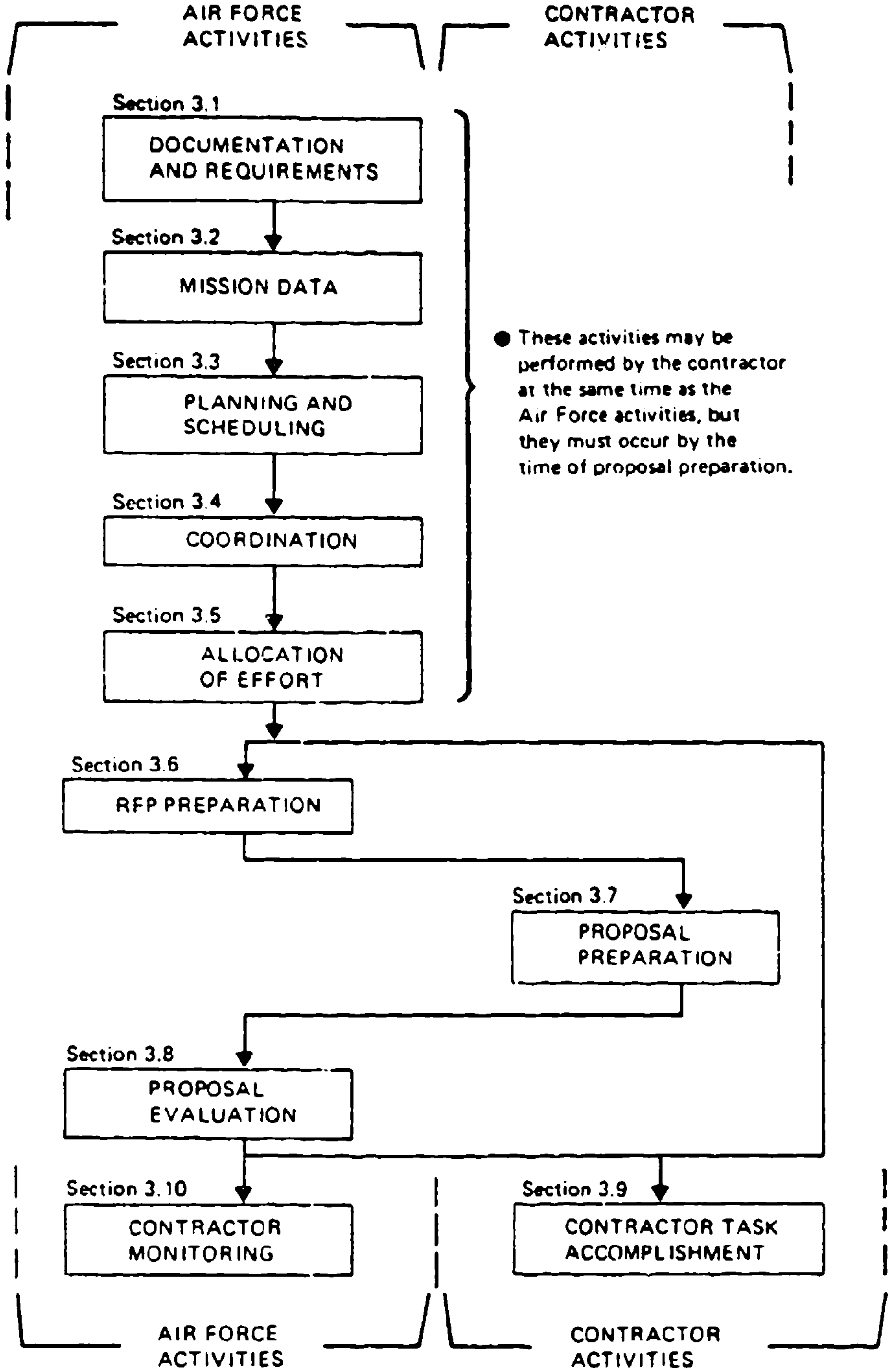


Figure 3.0-1. HE Activities During System Acquisition

the Air Force. They are not actually required to be performed by the contractor until the "proposal preparation" activity. However, it is recommended that these activities, as performed by the contractor, occur at approximately the same time that the Air Force is performing them. One way to accomplish this is with the performance of contractor study contracts.

This guide also includes a section (2.0) which is intended to assist the Air Force Program Element Manager, SPO, and contractor Program Manager. It is recommended that that section be reviewed also for the purpose of obtaining a different point of view to the major system acquisition process.

3.1 Documentation and Requirements

The specification and justification of HE requirements are critical to the successful accomplishment of the HE effort. The contractor's requirements, as indicated in appropriate documentation, are derived from the Air Force's requirements. The requirements which direct the Air Force are more general and slightly different from the more detailed contractor requirements.

3.1.1 Air Force Requirements

As indicated in Paragraph 2.1.1, these requirements derive from Department of Defense Directive 5000.1, Subject: Major System Acquisitions (Ref. 8); AFR 800-3, Engineering for Defense Systems (Ref. 5); and AFR 800-15, Human Factors Engineering Management (Ref. 1). Although this guide is directed toward the HE task rather than the complete HFE effort, AFR 800-15 explains the relationship between the two subjects.

The job of the Air Force HFE manager usually includes the HE task. Occasionally, there will be separate Air Force managers who specialize in training, training equipment, personnel requirements, or biomedical data.

As discussed in paragraph 2.1.1, MIL-H-46855 is particularly important to the Air Force and potential contractors. It is used primarily by the Air Force to place HE requirements into the contract for contractor compliance. Paragraph 3.6.2 describes how the Air Force may go about tailoring this specification for the HE portion of the program RFP.

In addition to the above indicated documents, there are many others which affect HE requirements. All documents which are applicable to the HE effort are listed in Table 3.0-1 along with the aspects of HE which they are related to and the nature of their applicablity, either primary, or secondary.

3.1.2 Contractor Requirements

Contractor requirements are provided directly by the contract statement-of-work (SOW), contract line items, and contract data requirements list (CDRL). The following Paragraphs 3.6 and 3.7 describe what the Air Force should include in the SOW and CDRL and how the contractor should use them when responding to an RFP. SOW items which are a part of a major system acquisition contract, MIL-H-46855 and MIL-STD-1472, are generally called out as contractual documents whose requirements must be adhered to.

MIL-H-46855 is the primary source for HE program requirements. This specification contains requirements for the performance of HE analysis, design and development criteria, and T&E.

MIL-STD-1472, Human Engineering Design Criteria for Military Systems, Equipment and Facilities, describes proper hardware design criteria that must be applied in order to inherently enhance operator/maintainer performance. All other documents shown in Table 3.0-1 should be considered by the contractor as providing information or design guidance only. DH 1-3 is the handbook most often referenced as a design guide and provides detailed data and amplification in its fulfillment of handbook objectives. Paragraph 3.6 describes the possible need to tailor MIL-H-46855 to be used as guidance for particular phases of the acquisition process. Contractor requirements described by the CDRL are also described in Paragraph 3.6.1.

Table 3.0-1. Document Applicability to Human Engineering

Requirements review documents \ HE Aspects	General requirements	Coordination functions	Level of effort	Schedule	Source data	Applications	Methodology techniques	Analysis	Design	Test and evaluation	Other
OMB Circular A-109	●										
Department of Defense Directives											
5000.1 Major System Acquisitions	X			●							
5000.2 Major System Acquisitions Process				●							
5000.3 Test and Evaluation										X	
Air Force Regulations											
80-14 Test and Evaluation		●		X						X	
800-2 Program Management				●							
800-3 Engineering for Defense Systems	X	●		●							
800-8 ILS Program for Systems and Equipment		●									
800-12 Acquisition of Support Equipment	●										
800-15 (and supplement 1) Human Factors Engineering and Management	X	X								X	
Military Standards											
MIL-STD-454 Standard General Requirements for Electronic Equipment	X										
MIL-STD-499 Engineering Management		●		●	●			X			
MIL-STD-882 System Safety Program for Systems . . .	●	●									
MIL-STD-1472 HE Design Criteria . . .	X							●	X	X	
MIL-STD-1388 Logistics Support Analysis	●	●				X		X			
MIL-STD-411 Aircrew Station Signals									X		
Military Specifications											
MIL-H-46855 HE Requirements for Military Systems	X	X	●			X	X	X	X	X	X
MIL-L-25467 Lighting, Integral Aircraft Instrument . . .									X		
H-series Data Items	X	X	X	X	X	X	X	X	X	X	X
AFM 50-2 Instructional Systems Development	X										
AFP 50-58 Handbook for Designers of Instructional Systems						●		X			
AFP 800-7 Integrated Logistics Support		●			X	X					
AFSCP 80-5 Guide for Advanced Development	X	●		●							
AFSCP 800-3 A Guide for Program Management	X	●		●						X	
Human Engineering Guide to Equipment Design	X						X	X	X	X	X
DH1-3 Human Factors Engineering	X	X				X	X	X	X	X	X

X Primary applicability ● Secondary applicability

3.2 Mission Data Sources

New system programs need a source or sources of mission data from which to initiate the analysis and design efforts. These data are in addition to the knowledge (described in the previous section) of which HE requirements are derived from what documentation. Mission data are needed to provide an overall background of program data from which to develop new program detailed requirements. Initially, new program requirements are based on particular previous program study reports and requirements developed from research and exploratory development program phases. The following two sections describe the sources of data for Air Force personnel and for contractor personnel.

3.2.1 <u>Air Force Sources</u>

There are essentially five sources of data available to Air Force personnel assigned to a new acquisition program. These are:

a. Data from AF development and planning organizations on studies determining feasibility.
b. Research and development (R&D) data developed by Air Force labs' system paper studies.
c. Data from other previously developed but somewhat similar programs.
d. Data obtained directly from the potential Air Force user commands.
e. And if all else fails, generation of the necessary program system analysis data from scratch.

During the normal evolution of an Air Force system program, AF development and planning organizations and laboratories will fund contractors to perform or develop (or both) paper/software analysis studies of the various proposed programs to help determine feasibility. This early (conceptual) program data should be available for review as study reports. The reports should contain direct reference to HE, HFE, Crew Systems, and/or the man-machine interface. If they do not, they should contain at least some notion of the system functional relationships with implications for the

man-machine allocation. A discussion of the planned crew system or displays and controls is generally available in the documentation. Mission analysis, including scenarios, flight profiles, and possible time lines will contain direct implications for operator tasks.

A second useful source which will contain considerably more detail but will not be as directly related to any particular need will be similar, previously developed programs. The chances are good that requirements for previous similar programs will be much the same in terms of: specifications and standards, planning and scheduling, coordination, allocation of effort, RFP data, and methods of contract monitoring. HE test results from the operational T&E effort may also be useful. As a word of caution, it is recommended that before previous program data are utilized, the success of the HE portion of the program be determined. Perhaps the best way to find sufficient previous program data is to seek out the HE managers of those programs. Both the details of what was required for that program and the success of the man-machine interface resulting from these requirements should be determined.

Additional sources of advice upon running an HE program are the HE manager's boss and/or associates who have had experience with major program acquisitions.

Regardless of previous experience on similar programs, the HE manager must contact the eventual program user command to determine their problems, needs, and recommended solutions. Questions such as the following or those associated with the DSARC milestone checklists (Ref. 14, DoDD 5000.2 and Ref. 2, AFSCP 800-3, Attachment 1) should be asked:

a) Why is the new system/program needed?
b) What trade-offs were (should be) considered in the man-machine functional allocation?
c) What does the user command anticipate the most critical operator tasks to be?

d) Is there any particular human performance in terms of time or reliability that is required? This will include these factors to be considered: Will human performance jeopardize mission performance; will system accuracy be degraded; will there be delay beyond time limits; will improper operation lead to system failure; will excessive maintenance downtime result; will there be degradation below required reliability; will there be damage to equipment; will system security be compromised; will injury to personnel occur?

e) What crew system problems does the user command anticipate (e.g., manning levels, skill levels, work loads, duty cycles, stress?)

f) What, if any, solutions do the user commands propose to solve their problem?

Although each of these questions should be asked, the responses should not be followed blindly. It is not the user command's job to design the new system. The HE manager must remember it is up to the contractor, with the SPO's guidance, to design the new system.

If for any reason the previous attempts to obtain source data for the HE program are unsucessful, the HE manager must generate these data for himself. He may, of course, call upon Air Force lab support if budget and personnel are available. The HE manager can start with the new program objective and the top level functions, as described in the SON (Ref. Section 2.5). These functions have been defined in order for the program to have been initiated. From these functions, lower level functions may be generated along with mission profiles and scenarios. The development of these data is time consuming but is very necessary in order to proceed with the program with a knowledge of the significant functions which affect the human engineering portion.

Part of the Air Force HE manager's job is to monitor specific technology areas continually for new man-machine interface concepts, e.g., automated speech technology. He should not have to start to develop or gather new technology data at the last moment. He must also stay abreast of major program decisions, made at the higher levels, in order that adequate HE research efforts can be planned and implemented.

3.2.2 Contractor Sources

The source of data from which the contractor HE effort starts on a new program varies in accordance with the system development phase. For the conceptual phase little, if any, human engineering data will exist which can be used directly to develop task analysis or man-machine hardware concepts. It will be necessary for the HE specialist to initiate development of these data (e.g., functional flow diagrams) from top level system functions and the mission objectives. Paragraph 3.9.4 (analysis) of this guide describes how this should be done. If the HE effort is addressed to the advanced development phase, several alternatives should exist for the contractor to obtain HE source data from which to start the effort.

Source data may be contained in the RFP or included as an attachment to the RFP. Advanced development efforts are usually sufficiently large that several program reports should be available for gaining quick source data information. The information generated during the conceptual phase of the program should be studied to determine the concepts for the man-machine interface. Many of these reports are available through the SPO while others are located at the Air Force Development Planning Organizations and labs where the research and exploratory or feasibility work was conducted or monitored. The contractor should not hesitate to ask the Air Force customer for any of his sources of existing HE related program data. The type of general program data which should be of assistance to HE users are the:

a. Mission Objective
b. System Requirements
c. Operational Performance Requirements
d. Environmental Factors
e. Mission Analysis
f. Information Flow
g. Functional Flow

If there is a general lack of program data availability to a potential contractor during a competitive program phase, and this lack is relatively independent of security classification considerations, this should be an indication that the potential contractor should not bid the particular program effort. As most contractors know, it is most difficult for them to initiate a major acquisition program without having performed a significant role in the preliminary research and exploration phases of the total program. The time to start gaining technical expertise is long before the RFP is issued.

Two additional sources of HE data are from previous similar programs and from contractor HE personnel who have worked on those programs. Previous similar program data should be examined because the methodology used to provide the HE data will probably be applicable to the new program. Often certain operator functions or tasks on a new program are nearly identical to those on a previous program. HE managers or analysts should be contacted to find out what documentation exists in total for the previous programs. They may be able to describe particular problems and solutions that may not have been documented but would be most appropriate to the HE effort on the new program.

After contract award (assuming the contract is single source) the contractor may discuss in detail the availability of source data with both the SPO and, with the SPO's approval, the user command. If not already answered, questions such as those in Paragraph 3.2.1 may be presented in order to gain a better understanding of the program HE problems, needs and solutions.

3.3 Planning and Scheduling

Planning and scheduling information is just as important to the program as the previously presented program mission source data. Planning and scheduling information is, however, considerably easier to obtain than the mission source data. A budget sufficient for performing and monitoring the HE effort is often not as easily obtained. This paragraph should be helpful in program planning, scheduling, and budgeting the HE effort.

3.3.1 Air Force Program Control

The program control function will be established by the program manager and will include data on planning and scheduling activities and on analysis of resources. This includes the programming of contractor, in-house, and review activities so that they mesh smoothly. It also includes documentation and management reporting. The major techniques used to perform this planning and scheduling are the event network and the work breakdown structure (WBS). (See Paragraphs 3.3.1.1 and 3.3.1.2)

It is the job of the HE manager to review the overall program schedule and WBS to insure that the HE functions as described in MIL-H-46855 and derived from his program source data effort (Ref. Paragraph 3.2.1) will occur at the proper time to be compatible with the other program functions. Every program has unique scheduling requirements.

Programs may be conducted in accordance with different management procedures. For example, although the intent of a program advanced development effort is to provide eventually an operational system, the details of the significant program phases are notably different from another type of system acquisition which also results in an operational system. AFSCP 80-5 (Ref. 29) and AFSCP 800-3 (Ref. 2) describe each of these management procedures. AFSCP 80-5 describes the first case where an advanced development program (Research and Development) evolves from research (6.1 element) to exploratory development (6.2 and on into advanced development 6.3).

If all goes well, the program then proceeds to engineering development (6.4) and operational system development. AFSCP 800-3 describes the second case where an acquisition system proceeds through the various major program phases following each of the appropriate DSARC milestone reviews and approvals. The program phases are conceptual, validation, full-scale development, and production. These phases correspond to the last four of the above five research and development program phases. The difference between these two methods of program management/scheduling is that the research and development programs (AFSCP 80-5) emphasizes experimental system demonstrations. They involve the development and test of advanced systems of experimental design to demonstrate operational feasibility or increased operational capability. There are, of course, programs which are combinations of the two described here. They may be managed/scheduled by either system (i.e., the 80-series research and development regulations and pamphlets or the 800-series acquisition management procedures regulations and pamphlets).

It is particularly important that the Air Force HE manager understand the type of program schedule so that he may understand the time-phased need for the major portion of the HE effort. Advanced development programs, by definition, have their major design reviews during the 6.3 advanced development phase. Other programs, run in accordance with the 800-series regulation procedures, have their design reviews during a corresponding later stage, 6.4 full-scale development. The major HE effort must occur during the design review phase of the program. However, it should be noted that it is seldom too soon to initiate the HE portion of any program and AFSCP 800-3 specifically calls out the need for design reviews and HE planning during the validation phase, prior to the preliminary and critical design review phases (full-scale development). ASDP 800-2 (Ref. 30) should be useful to both ASD personnel and others to understand HE planning and integration into the major acquisition process. It includes a flow chart which depicts general milestones and indicates where ASD human factors makes contributions.

Work breakdown structure index	Program	C-XXA				RFP no. ____ Contract no. ____			Date
Line no.	Work breakdown structure elements/tasks 0 1 2 3 4 5 6 (Level)	Material program code and/or WBS code	Eng. Dev.	Prod.		Eng. dev. Prod. cont. line item	Eng. dev. SOW paragraph number	Prod. SOW paragraph number	Specification number
336	System Project Management	010600	X	X		0001	010600		
337	Systems Engineering Management	010610	X	X			010610	010610	
338	Configuration Development	01061A0	X				01061.1		
339	Baseline	01061AA	X						
340	Trade Studies	01061AB	X						
341	Design Definition	01061B0	X				01061.1		
342	Specifications	01061BA	X						
343	Design Requirements and Objectives	01061BB	X						
344	Configuration Description	01061BC	X						
345	Trade Studies	01061BD	X						
346	Design Verification	01061C0	X				01061.1		
347	Design Reviews	01061CA	X						
348	Reliability/Maintainability	01061D0	X	X			01061.1	01061.2	
349	Experience Retention	01061E0	X	X			01061.1		
350	Safety Engineering	01061F0	X	X			01061.1.2		
351	Survivability/Vulnerability	01061G0	X	X			01061.1.3		
352	Human Factors Engineering	01061H0	X	X			01061.1.6		
353	Human Engineering	01061HA	X	X					
354	Biomedical	01061HB	X	X					
355	Manning	01061HC	X	X					
356	HE Test and Evaluation	01061HD	X	X					
357	Technical Integration	01061J0	X	X					
358	Mission Analysis	01061K0	X	X					

Figure 3.3-1. Sample Work Breakdown Structure (WBS)

3.3.1.1. Work Breakdown Structure

The WBS is a numbered and indentured list of the development efforts to be conducted in the program, their subdivisions, and their interrelationships.

The WBS is useful to both the Air Force and contractors for planning, costing, and scheduling. The format is determined by the SPO and MIL-STD-881A (Ref. 31). It should reflect the specific goals of the program and the resources available to meet them. Figure 3.3-1 shows a partial example of a WBS for a hypothetical program. The location of HE or HFE in relation to the other WBS elements may vary considerably from program to program.

3.3.1.2 Event Network

The event network is a time phased work diagram. It is prepared, based on an analysis of the WBS and an analysis of the sequence of tasks and reviews required to carry out the proposed development efforts. Each phase of the program should be broken down into blocks, each representing a discrete event. A discrete event is a portion of the program involving a single function, such as review, test, design and engineering, or procurement, or in some cases two or more closely coordinated functions, performed by a single group, such as a contractor or an Air Force facility, in a period of time that is also a discrete unit in the total sequence of events. That is, a discrete event may take place at the same time with other events or in series with the other units chronologically. Thus, similar functions may be repeated in the various phases. In such cases, they are listed as separate events in the network.

The event network should identify the following items:

a) The flow of events, including those that are performed in parallel and those performed in sequence with other events.
b) The program functions to be performed in-house by the Air Force and those to be performed by contractors.
c) The level (OSD, HQ USAF, HQ AFSC, or other) of each guidance and review task.

3.3.1.3 System Baseline

In addition to the WBS and event network, another program management tool that must be monitored is the system baseline. This is a description of the system being developed in terms of program requirements, design requirements, and configuration. These aspects of the baseline may be established at any point in a development effort to define a formal departure point for control of future changes in the program or the design of hardware. The baseline is documented by approved program and contract documents and by specifications and drawings prepared by the contractor.

3.3.1.4 Air Force Budget

The Air Force HE manager's budget is of major concern in terms of what he can do to monitor the program and what support he may obtain from Air Force labs. His duty as system acquisition HE manager is generally in addition to other duties. The problem of budget is therefore a personnel one of percent time allocation to a job rather than total man-hours available. The Air Force HE manager determines the contractor's budget indirectly in that the more tasks he requires the contractor to perform as part of the contract, the more budget the contractor HE personnel must have. There is a secondary effect on the Air Force HE manager in that the more tasks the contractor performs the more Air Force review is required.

3.3.2 <u>Contractor Program Control</u>

During recent years, the scheduling and budget aspects of system acquisitions has become paramount, even to the cost of system performance, if necessary. In order to maintain complete control of total program scheduling, program subsystem and discipline managers must schedule their particular tasks in relation to the major tasks/events of the total program. Overall program control is established by the contractor program manager. This includes analysis and design review activities, WBS, documentation, and management reporting.

The HE manager will perform HE planning and scheduling by starting with the total program milestone chart. He will add the HE data requirements from the CDRL and the HE tasks from MIL-H-46855. In general, these tasks should include operations analysis, definition and allocation of system functions, potential equipment selection, task analysis, design criteria application, equipment procedures development, test and evaluation, and any significant studies or simulations. Inputs and outputs of these tasks should be included. The chart should be started by scheduling HE products at the latest time that they can be used effectively. The start points and time span for HE analysis and other tasks by estimating the time it will take to complete each task. If manpower utilization has not been planned, an approximate estimate should be made based on previous program experience (yours or others). Based on the HE task start times, schedule all data inputs to the HE tasks. This first schedule may not work but it is a necessary starting point for iterations. Manpower needs may have to be adjusted; some tasks may be reduced to meet the schedule requirements of the overall program.

3.3.2.1 Contractor Budget

The recommendation of accurate manpower required to perform the HE program tasks is one of the most needed and most difficult portions of this guide to provide. The best teacher of task man loading is experience. The following chart, Figure 3.3-2, has been developed to assist HE managers who are new to the job of estimating HE work level effort in relation to analysis and design tasks to be performed. At best, the chart must be considered as not precise. There are too many variables involved to lay out an accurate allocation of scheduled HE manpower. If HE managers have had any experience with this kind of budgeting and scheduling, they may be better off to disregard the chart and rely on their experience. The major variables in the chart are the types of analysis and design to be performed and the program schedule. The manpower estimates have been made as percentages of total manpower available to do the HE tasks. The available manpower could vary from less than 1 to 20 persons depending on the HE portion of the total program and the total program size.

Note: Assume no separate operations analysis effort
assume small precontract effort

Time (% of schedule shown)

Types of HFE activities	0–10	10–20	20–30	30–40	40–PDR	PDR–60	60–70	70–80	80–90	90–CDR
Operations analysis:										
Scenarios	25%	5%				5%				
Mission profiles	15%	10%				5%				
Definition and allocation of system functions										
Functional flows	25%	25%	20%	10%		5%				
Operator capabilities estimation	10%	10%	5%							
Function allocation	10%	20%	30%	25%	20%	10%	10%			
Equipment identification		10%	5%	5%		5%				
Analysis of tasks										
Gross task analysis		5%	20%	20%	25%	10%	10%	5%		
Critical task analysis				15%	20%	20%	20%	20%	15%	10%
Workload analysis					10%	10%	20%	20%	20%	20%
Design support				10%	10%	15%	25%	40%	50%	55%
Supervisory and clerical	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Total HE effort	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 3.3-2, Hypothetical Example of Program Manpower Estimates (up to time of critical design review (CDR))

The numbers across the top of the chart represent percent of the schedule shown. Depending on the program, they could represent weeks or days. The two milestones are the preliminary design review (PDR) and the critical design review (CDR. The PDR is often referred to as the initial design review. It is the point in the schedule where the design specifications and drawings receive preliminary approval by the customer. The CDR, or final design review, is generally the time at which the design receives the approval from the Air Force.

As indicated, there are variations in the types of HFE analysis and design required. Operations analysis may or may not need to be performed, depending on the program organization and what work has been performed prior to this effort. Some programs will require more analysis in some areas and less in others. For example, programs with large operational crews tend to require more emphasis on man-machine functional allocations and workload analysis.

A rule of thumb that is frequently used by contractors as a budget starting point for the HE effort is 1% of the total initial 6.2 exploratory development, if there was one, or 6.3 advanced development for large programs. There are several variables that can increase or decrease this budget amount. It assumes a complete HE effort in accordance with MIL-H-46855 and MIL-STD-1472. It assumes an average size operational and maintenance crew. As the program evolves into 6.4 full scale engineering development, this percentage drops significantly due primarily to the higher expenditures for FSED rather than a diminished HE effort. The single largest variable that affects the budget is the contractor program manager. If insufficient budget is provided to perform all of the HE tasks required by the SOW, he must be informed of the consequences of the inadequate budget. If he is not convinced (Reference Section 2.3, HE Value), priorities must be established for each of the HE tasks and the total level of effort must be adjusted accordingly.

3.3.2.2 Contractor Organization

The combination of planning, scheduling, WBS, and budget implies an organization of HE specialists to perform the work. The HE manager must establish an HE organization which reports (indirectly) to the contractor program manager.

The HE manager who is in charge of the organization should be thoroughly experienced from significant man-machine efforts on previous major system acquisition programs. The HE manager should be responsible for the primary control, direction, supervision and management of the technical HE aspects of the program. He should perform himself, or direct the accomplishment by personnel directly under his supervision, the technical tasks of the HE program. The HE manager should be responsible for the implementation of the following HE program tasks:

a) Provide a single point of contact for HE related matters.
b) Revise and provide input to all plans and contractual documents related to HE.
c) Maintain approval authority on all items related to HE contained in the CDRL.
d) Coordinate HE related matters with contractor program management and all program elements and disciplines.
e) Provide for investigation and reporting of all test and evaluation human initiated failures including all incidents and accidents related to HE.
f) Participate in all system requirements and design reviews to assure that: all HE specified requirements are complied with; HE schedule and CDRL deliveries are compatible; HE analysis techniques permit integration and use in a cost-effective manner; and established HE criteria are consistent with cost, performance and scheduling requirements.
g) Provide informal technical support to program engineering activities.
h) Participate in program baseline configuration control activities including the review and approval of all system configurations and changes thereto that involve the human operator and/or maintainer.

3.4 Coordination

Having determined what HE tasks are required (Source Data) and what the program schedule is (Planning and Scheduling), the HE manager must coordinate the necessary HE program tasks with the Air Force program manager and others. Of all the disciplines involved in the design and development of a weapon system, HE requires the most coordination, primarily laterally to other disciplines but also vertically to management. Because the HE "raison d'etre", the human element, is a part of most program subsystems, most program disciplines are significantly affected, and therefore, should require considerable coordination.

3.4.1 With Program Manager

The Air Force HE manager must tell the program manager what HE can do for the program. Included in this should be data as to previous program experiences (Ref. Section 3.2, Mission Data Sources) and scheduling data. The Air Force HE manager should be sure that the program manager understands the need for MIL-H-46855 and MIL-STD-1472 (if they are required). In particular, the program manager should understand the need for contractor HE sign-off on all drawings having an impact on the man-machine interface (Ref. Section 3.5 of MIL-H-46855). The knowledge that the Air Force program manager will support this requirement will assure that the contractor program manager will adhere to it and the resulting hardware designs will indeed include the necessary HE design criteria.

If there is any problem with the inclusion of HE and HFE items in the WBS, they should be discussed with Air Force program manager and the Air Force program control personnel as soon as possible. The WBS created by the Air Force should dictate that used by the contractor. Any problems in the original will only cause problems for the contractor HE effort later on. The WBS indenture level that calls out HE should be as high as possible in order to provide emphasis on the importance of the effort.

In similar manner to the above, the contractor HE manager must coordinate with the contractor program manager to insure he has sufficient budget. The contractor HE manager must tell the program manager what HE can do for the program. Included in this should be data as to previous program experiences and scheduling data. The need for MIL-H-46855 and MIL-STD-1472 (if they have been called out) should be explained. In particular, the program manager should understand the need for HE sign-off on all drawings having an impact on the man-machine interface (Ref. 3.5 of MIL-H-46855). This requirement must, of course, be supported by the Air Force program manager.

3.4.2 With Other Technologies

The HE effort affects every portion of the total system that has a man-machine interface. HE personnel apply the operator/maintainer capabilities and limitations in studies and specifications to the design and development of the weapon system and its support equipment. Upon initiation of full-scale engineering development, contractor HE organizations frequently assign specific HE personnel to support specific project design organizations (e.g., avionics, crew station design, or communications). In this way the individuals may become particularly expert at dealing with particular types of HE problems associated with particular design groups (e.g., speech interference levels and communication problems). Appropriate HE design criteria for each type of hardware will be correctly applied.

In coordination with personnel requirements specialists, HE will use the operator/maintainer task analysis to develop manning requirements to operate and maintain the weapon system. HE will participate in trade studies to arrive at the most efficient and cost effective man-machine interface. Typically, HE will also work with training specialists to develop the required skill and numbers of personnel, the training and training support necessary for the operation and maintenance of the entire system. HE works with his medical personnel on personnel safety and life support matters. Coordination with such disciplines as system safety, maintainability, and reliability is not just to ensure that the necessary system requirements are met but that they are not duplicated by more than one group.

This coordination is to insure that other disciplines are receiving the proper support from HE and vice versa. In addition to the program manager, the disciplines/technologies illustrated in Table 2.2-1 should be contacted to inform them of the analysis, design, preliminary procedures, and test support that HE has to offer. The HE effort must be integrated into the total system program. Table 3.4-1 shows the relationship of several important HE functions to other related program functions and to the major acquisition phases as defined by three sources. The deployment phase, which is defined by AFM 11-1 (Ref. 12), is not shown on this chart. Both a typical and important example of such coordination would be the inputs to HE in regard to mission operations analysis or outputs from HE analysis as to the proper crew size for a multi-engine aircraft. If there are subsystems which will be severely affected by the results of the HE effort, the appropriate Air Force managers should be forewarned. It is, of course, up to the Air Force HE manager to see that the particular HE analysis, design, or test effort is well documented for presentation to the affected subsystem group.

3.4.3 With Other Services

Although not required, coordination with both the Army and Navy manager personnel is strongly recommended. There is sufficient probability that either they or the Air Force would benefit by the interchange of data on similar aspects of their different programs. Both methodologies and design requirement solutions should be discussed. The participation in HE tri-service, NASA and industry conferences/meetings is encouraged for the exchange of useful data.

3.5 Allocation of Effort

The normal allocation of the HE effort is directly from the Air Force through the contract SOW to the contractor. However, there are several possible variations on this. The following subsections present a few alternatives to the normal HE work allocation.

Table 3.4-1. Relation of HE Functions to Other Program Functions and Acquisition Phases

Program phases	Conceptual		Validation	Full-Scale Development	Production
AFM 11-1	6.1 Research	6.2 Exploratory Development	6.3 Advanced Development	6.4 Full-Scale Engineering Development	6.6 Production and Deployment
AFSCP 80-5 DODD 5000.2		Program Initiation	Demonstration and Validation	Full-Scale Engineering Development	Production and Deployment
Human engineering acquisition functions	• Experiments • Studies • Mockups • System analysis • Task analysis • Plans		• Task analysis • Detailed design • Mockups • Prototypes • Demonstrations • Procedures Development	• Detailed design • Prototypes • Preliminary evaluation • Demonstrations • Procedures Development	• Formal T&E
Human engineering interfaces with related areas	• Biomedical • Personnel Requirements • Maintainability • Reliability • Safety • System Engineering		• Biomedical • Personnel Requirements • Maintainability • Project Design • System Engineering • Safety and Reliability • ISD/Training • Preliminary life-cycle costs	• Biomedical • Personnel Requirements • Logistics • Publications • Maintainability • Project Design • Safety and Reliability • ISD/Training • Life-cycle costs • Technical T&E	• Biomedical • Publications • Maintainability • Safety • ISD/Training • Operational T&E
Objectives	Technology research	Paper studies	Critical issues evaluated	Engineer evaluation DT&E and OT&E	Operational hardware
DOD program milestones		Milestone 0 (MENS) Approval of mission need and program initiation	Milestone I (DSARC I) Approval to demonstrate selected alternatives	Milestone II (DSARC II) Approval for Full-Scale Engineering Development and limited production for OT&E	Milestone III (DSARC III) production release decision

Table 3.4-1. Relation of HE Functions to Other Program Functions and Acquisition Phases

Program phases	Conceptual		Validation	Full-Scale Development	Production
AFM 11-1 AFSCP 80-5	6.1 Research	6.2 Exploratory Development	6.3 Advanced Development	6.4 Full-Scale Engineering Development	6.6 Production and Deployment
DODD 5000.2		Program Initiation	Demonstration and Validation	Full-Scale Engineering Development	Production and Deployment
Human engineering acquisition functions	• Experiments • Studies • Mockups • System analysis • Task analysis • Plans		• Task analysis • Detailed design • Mockups • Prototypes • Demonstrations • Procedures Development	• Detailed design • Prototypes • Preliminary evaluation • Demonstrations • Procedures Development	• Formal T&E
Human engineering interfaces with related areas	• Biomedical • Personnel Requirements • Maintainability • Reliability • Safety • System Engineering		• Biomedical • Personnel Requirements • Maintainability • Project Design • System Engineering • Safety and Reliability • ISD/Training • Preliminary life-cycle costs	• Biomedical • Personnel Requirements • Logistics • Publications • Maintainability • Project Design • Safety and Reliability • ISD/Training • Life-cycle costs • Technical T&E	• Biomedical • Publications • Maintainability • Safety • ISD/Training • Operational T&E
Objectives	Technology research	Paper studies	Critical issues evauated	Engineer evaluation DT&E and OT&E	Operational hardware
DOD program milestones		Milestone 0 (MENS) Approval of mission need and program initiation	Milestone I (DSARC I) Approval to demonstrate selected alternatives	Milestone II (DSARC II) Approval for Full-Scale Engineering Development and limited production for OT&E	Milestone III (DSARC III) production release decision

3.5.1 Air Force Allocation

Although major system requirements are generally assigned for development by major contractors, the assignment of all HE functions to the same contractor is not automatic. The major advantage in keeping the allocation of HE tasks with the prime contractor is simply minimization of the coordination effort. However, it is possible that the major contractor does not have the capability to perform a complete or even a partial HE effort. The contractor may propose the apportionment of HE tasks to other sources. Or the Air Force HE manager may decide that the best capability to perform certain HE tasks exists within Air Force labs or test centers. The Air Force HE manager may also select another contractor to perform the HE effort. Numerous small HFE companies provide complete HE services in analysis, design criteria, and testing. Although companies such as MITRE and TRW do not provide the complete HE effort as defined in MIL-H-46855, they do provide a thorough knowledge of major system acquisition and of HE effort monitoring.

In addition to the problems of determining whether in fact the Air Force or other sources do have a better capability to provide a portion of the HE effort, the Air Force HE manager takes on the added tasks of coordination between split HE effort allocations. This also requires that the proper budget is provided along with the time and personnel for the lab/test center to do the job.

3.5.2 Contractor Allocation

It is an unusual situation that a major Air Force system acquisition contractor would allocate a complete HE effort to a subcontractor or even an associate contractor. However, the use of consultants, subcontractors, and associate contractors to perform portions of the total HE program is not unusual. Several competent consultants are available to work specialized aspects of HFE, particularly in the biomedical area. A few consultants may be helpful in the area of automatic (computer) design and analysis techniques.

If a major acquisition contract is split between two or more major contractors, and one is not designated as prime, an integrating agency or contractor is necessary to coordinate the effort. The allocation of HE effort should be as described in a plan developed by the integrating agency/contractor. If required, associate contractor HE plans should be incorporated in some manner into an integrated HFE plan. This integrated plan should describe the level of effort each associate contractor must maintain. It must describe the HE tasks (including task analysis formats) each must perform and the HE data outputs from those tasks, which will be submitted to the integrator in accordance with the HE program schedule. The plan should be prepared in the same manner as described in DI-H-7051.

The HE effort to be performed by subcontractors is proportional to the size of their contract and the nature of their work. It is primarily the job of the prime contractor HE manager to decide how much HE the subcontractor shall perform. Because the prime contractor is always responsible for the total HE effort, both prime and sub, he may wish to have more of the total effort done by his organization. Frequently, when the requirement for MIL-H-46855, including the HE plan, is levied on the prime contractor, they will not pass the requirement on to the subcontractor(s). Nearly always when the requirement for MIL-STD-1472 is levied, this will be passed on down to the sub(s). The reason for this is that it is both easy and cost effective to informally coordinate between a prime and subcontractor to insure that HE methodology (i.e., MIL-H-46855) is performed correctly. It is extremely difficult to redesign subcontractor equipment to incorporate HE design criteria (ie., MIL-STD-1472) which had not been required originally. It is easy and cost effective to require its original application.

3.6 RFP Preparation

Based on all of the previously developed source data and allocation decisions, the Air Force HE manager is now able to provide HE inputs to the RFP. These inputs should generally be provided to three separate portions of the RFP. These are the SOW, preliminary system specification, and the CDRL. Other possible sections which may contain HE data are the proposal preparation instructions and evaluation factors for award.

3.6.1 HE RFP Inputs

Because this guide is directed primarily toward major system acquisitions, the SOW should contain a MIL-H-46855 and MIL-STD-1472 call out under the "Reference Documents" section. It should also contain words to the effect that these two documents are required and the HE program should be run in accordance with their direction.

The preliminary system specification should contain a paragraph (generally Paragraph 3.3.7, in accordance with MIL-STD-490, Ref. 32) which calls out the Human Performance/Human Engineering requirement including the specification and standard. Depending on the phase of the acquisition, the budget, the acquisition strategy, and with the approval of the Data Management Officer and the program manager, the HE program manager may include any or all of the Human Engineering Data Items (see Table 3.6-1) in the CDRL.

TABLE 3.6-1 HUMAN ENGINEERING DATA ITEMS*

a.	DI-H-7051	Human Engineering Program Plan
b.	DI-H-7052	Human Engineering Dynamic Simulation Plan
c.	DI-H-7053	Human Engineering Test Plan
d.	DI-H-7054	Human Engineering System Analysis Report
e.	DI-H-7055	Critical Task Analysis Report
f.	DI-H-7056	Human Engineering Design Approach Document-Operator
g.	DI-H-7057	Human Engineering Design Approach Document-Maintainer
h.	DI-H-7058	Human Engineering Test Report
i.	DI-H-7059	Human Engineering Progress Report

*All approved Standard Data Items are in DoD 5000.19L

DI-H-7051, Human Engineering Program Plan, is the most inclusive HE Data Item and may be used alone. It may be noted that MIL-H-46855 requires HE Program Planning. However, the only reasonable way to specify a HE Program Plan is to list such a requirement (DI-H-7051) in the CDRL.

The major portion of the contractor HE effort to be performed should be briefly described in the SOW. In addition to the HE specification and standard call outs, this section should indicate the particular type of work the Air Force HE manager feels must absolutely be performed. This may include trade-offs (e.g., crew size), mockups or simulations. The recommended methodology to be used by the contractor may also be indicated in the SOW. If there are any particular HE objectives, such as crew size or performance, these should be so stated. It is generally better to include all the HE efforts for the program in a single section of the SOW rather than apportion them to each of the applicable subsystems. The contractor should respond in the same manner and the total effort may thereby be prepared and reviewed with less total effort.

Whereas the work to be required in the SOW as described by the Air Force HE manager must be within reasonable limits of what the total contractor budget will allow, the contractor counterpart of the Air Force HE manager would generally prefer being required by the contract (or RFP) to do too much rather than too little. The RFP effort required of the Air Force HE manager is by far the most significant single factor in insuring an adequate HE program. All program requirements must be included in the RFP package initially. The cost to add requirements at a later date with an engineering change proposal (ECP) is generally prohibitive in comparison to the gain from the added contractor responsibility for an additional task.

During the RFP preparation, a source selection plan should be prepared by the project office. Included in the plan and the RFP should be evaluation criteria and standards which indicate a proposal score given, in part, for the contractor HE effort. This score allocation to HE should insure a best effort contractor response to the HE aspects of the RFP.

3.6.2 Tailoring

During the past few years, the subject of specification tailoring has gained popularity; presumably because of DoD Directives and the well known OMB A-109 circular describing major system acquisition methods. The general notion of specification tailoring is based on the concept that the reason many systems acquisitions cost so much is that they are designed and built per specifications which require design constraints which in many cases are not really 'useful' or appropriate either to that particular program or for a particular design phase. Tailoring is an attempt to modify specifications to require only that which is useful to the planned system acquisition phase.

Whereas there is little question as to the short term cost effectiveness of HF specification tailoring, there is serious doubt as to the effects of this tailoring on life cycle costs (LCC's). Before tailoring is accomplished by either the Air Force or contractor, a few extremely significant factors must be considered:

a) The probability that the program will complete the full acquisition cycle.
b) The nature of the specification tailoring savings as short term only, long term only, or both short and long term.
c) The amount of short term savings due to tailoring.
d) The cost to change the system design to meet long term system performance requirements (e.g., maintainability and operability) not necessary for the initial acquisition phases.
e) The probable increased life cycle costs associated with waiving the reliability, maintenance, and operability requirements normally specified for an operationally deployed system.
f) The comparison between items c), d) and e) above.

The answer to the first factor is "most probable". Very few programs ever fail to pass their Defense System Acquisition Review Council (DSARC) milestone review meetings. Therefore, both long term (LCC) and short term savings are significant. If the savings are short term only, they need to

be balanced against possible increased life cycle costs that they could cause. These costs could be for engineering change proposals (ECP's), system design revisions, operator or maintainer errors resulting in costly failures, equipment malfunctions, or safety hazards.

Rather than recommend tailoring of MIL-H-46855 and particularly MIL-STD-1472 during the RFP preparation, it is recommended that any tailoring to be performed, if any, be accomplished by the contractor in his proposal response (to the RFP). The Air Force should specify both specifications as is and invite tailoring of them in accordance with DI-H-7051 (HE Plan).

The total notion of tailoring as applied to HE is somewhat ironic in that MIL-H-46855 has always clearly stated that it may be invoked on contracts either in its entirety or selectively. In his HE Plan, the contractor has always described those HE tasks which he determines are most cost effective to perform. In accordance with MIL-H-46855 and the HE Plan Data Item (DI-H-7051), the contractor provides what he feels is a tailored version of the HE tasks to be accomplished (or not to be accomplished) for the program.

If the program is not a major acquisition, the Air Force HE manager should determine the general applicability of MIL-H-46855 to the particular program. The suggested method of doing this is included as an appendix to MIL-H-46855. It should be noted that if users of this guide are working with major systems acquisitions, MIL-H-46855 should be applied.

It should be further noted that if an Air Force HE manager has already been assigned to a program, the chances are high that MIL-H-46855 should also be required. Conversely, if MIL-H-46855 is not required, the need for the HE manager is questionable.

In a somewhat similar manner, the possible need to tailor MIL-STD-1472 is superfluous. The application of the standard in its entirety to a program costs little if applied early. The few situations which might arise that would cause a high system cost or performance decrement as a result of

application of the criteria are easily solved. Each of these deviations from MIL-STD-1472 design criteria are presented during design reviews to the Air Force customer on a design criteria deviation request sheet. This deviation request may or may not be a part of an existing engineering change proposal (ECP). The deviation, cause, and implications are summarized and if approved, which they generally are, signed off by the Air Force. If not approved, the criterion is incorporated into the design, along with the increased system costs required to implement the design requirements.

Where MIL-STD-1472 criteria are clearly not applicable due to absence of the particular hardware or system functions for which the criteria were intended, it is not necessary to call out all the exceptions. This task is generally too tedious to be of value. The error of omission in not calling out the application of pertinent criteria is more serious than the error of commission, calling out criteria which would apply to nonexistent hardware or system functions. The latter mistake is easily forgiven and, if necessary, can be provided for in the above described criteria deviation request forms which should be described in the contractor's HE program plan. The error of omitting the requirement for appropriate design criteria could easily lead to a costly engineering change proposal (ECP), or worse yet, to ignoring the needed criteria and risking the consequences of the degraded man-machine performance.

As previously indicated, the most fruitful area to perform HE tailoring is in the HE program Plan (DI-H-7051). Other data items may also be tailored. The tailoring of the data items should correspond to the tailoring of MIL-H-46855 and its requirements on the contractor. The data items may be omitted if not necessary or they may be modified to delete any ineffective or costly portions which do not apply to the particular program.

3.6.3 Draft RFP's

Frequently, in order to create a better quality RFP, a draft RFP is issued to potential competitors for their review and comment. Such drafts have advantages in that the Air Force can try out requests for particular program tasks, provisions, or methodologies. Industry feedback on draft RFPs has the potential for effecting substantial savings by pointing out unnecessary constraints. The contractor's responses to the final RFP are generally of better quality since they have had more time to work the requested proposal problem. The Air Force HE manager should participate in the draft review in order to suggest the kind of effort that he feels should be requested in the RFP.

3.7 Proposal Preparation

If the Air Force has issued a draft RFP, the contractor responds by providing a critique and suggestions. The contractor is aware of the total problem and should produce a better quality proposal. The contractor HE manager should participate in the draft review in order to suggest the kind of effort that he feels should be requested in the RFP.

Once the RFP is officially issued, the decision as to how to respond is invariably made by the contractor program manager within the limitations of the proposal evaluation criteria supplied with the RFP. The program manager may simply choose to respond in kind to each of the requested tasks listed in the RFP statement of work (SOW). As a minimum, the contractor must state agreement with the SOW and/or take exception to those portions he does not wish to comply with. The contractor should also indicate his acceptance of the CDRL item. Frequently, this means providing a preliminary copy of the HE Plan in accordance with MIL-H-46855 and DI-H-7051. If the Preliminary HE Plan is required, most of the proposed HE effort may be contained in the plan. If the plan is not required, the HE effort should be described in the technical portion of the proposal. In some cases, an HE Plan is submitted although not required per the RFP. In any case, the following subjects should be included in the Plan or the HE portion of the proposal:

a) Procedures that are proposed for complying with MIL-H-46855 requirements. This includes anticipated trade studies and analysis, design, evaluation techniques intended to be provided.

b) The company's organizational elements and (if possible) personnel selected to implement the HE program.

c) The HE efforts accomplished (and lessons learned) during previous program phases should be summarized.

d) The proposed HE participation in simulation, mockups, equipment detail design, testing, and verification should be described.

e) Special HE objectives (e.g., crew size and performance) and anticipated problems should be included along with the proposed means to meet these objectives and solve these problems.

f) A time-phased edule showing initiation and completion dates of significant lestones.

When the plan is used to describe the HE effort, this effort should be an integral part of the total program management and engineering effort. The plan should include details of the implementation of each task identified by the tailored application of MIL-H-46855. The plan should describe the requirements for HE management required to support the program through the total period of the contract. The plan should detail the HE interfaces with all levels of program management. It should show clear evidence of specification tailoring consideration and of design to cost and design to life cycle costs. The cost of imposing HE requirements should be evaluated against the benefits that will be realized.

After the issuance of the RFP and before the contract award, the Air Force evaluators are no longer free to converse with prospective contractors on an informal day-to-day basis. From that point on, everything will be documented and coordinated through the appropriate contracting officer.

3.8 Proposal Evaluation

The Air Force HE manager should play an active role in the customer proposal evaluation process. He must participate as a member of the source selection team to insure that the contractor's intended approach to dealing with the system man-machine interface meets the criteria described in the previous Section (3.7). The Air Force HE manager must develop the facts upon which to base source selection. He must be able to determine whether the potential contractor understands what needs to be done. This includes understanding of the HE requirements and scope and magnitude of the project, realism of approach, risk assessment, and life cycle cost implications. The HE contractor must clearly show that the requirements are recognized, that a preliminary analysis was made in arriving at the approach, and that the requirements will be satisfied in a timely and cost-effective manner. The areas in which trade-off decisions will need to be made should be identified with candidate alternatives and the rationale and schedule for their selection. The Air Force HE manager must check to insure intended compliance with SOW, system specification, and CDRL requirements. If a preliminary HE Program Plan is called for, much of the evaluation can be made by a thorough review of the plan. Evaluation ratings and rankings must be in accordance with the overall source selection plan established for the system.

The contractor's directly applicable and related HE experience should be evaluated. The contractor must clearly indicate the relevance of experience gained in similar programs of equal or greater complexity. The contractor may wish to provide "lessons learned" and to show how his experience will benefit the particular proposed program. The relation of HE to other disciplines must be indicated as well as the relation of HE to program management. However, the later relationship should not be evaluated as being right or wrong but should be presented to the Air Force customer for his information. Consideration of design to cost or design to life cycle cost as it affects HE should also be evident in the proposal.

3.9 Contractor Task Accomplishment

After the award of the contract, the major portion of the program effort is in the hands of the contractor. Along with several other technologies, HE must refine its program planning and scheduling ef[illegible]. It must initiate the development of system requirements, cond[illegible] [illegible] [illegible]rade studies, participate in the design of the program deve[illegible] [illegible]el, and evaluate the design model through the use of appropriate tes[illegible] [illegible]iques.

3.9.1 Meetings

Within a few weeks of the contract award, a guidance meeting should be arranged between the Air Force and contractor. The purpose of this meeting is for a face to face discussion of what each of the two parties feels is the necessary HE (or HFE) effort for the program. The Air Force should tell the contractor his evaluation of the HE inputs to the proposal. If an HE Plan was submitted, this evaluation will be directed primarily to that item. The Air Force HE monitor should provide the contractor with detailed guidance as to the problems and the needs the HE effort should address. The meeting may be used to discuss customer sources of analysis input data not previously known to the contractor. The contractor choice of analysis, design, and test techniques may be reviewed. Significant human performance requirements should be defined to avoid later misunderstanding.

HE will also participate in program design reviews such as the PDR & CDR. Results of HE efforts, including applicable trade studies and critical task analysis, will be reported. Derived HE design criteria and applicable HE design requirements should be presented.

3.9.2 Detailed HE Plan

If a Preliminary HE Plan was required as a part of the total program proposal, a Detailed HE Plan should be prepared subsequent to the customer-contractor guidance meeting and submitted as a part of the

Program Plan for the system (Ref. DI-H-7051). When this plan is approved by the SPO, it may be used by the contractor to direct his program efforts. If any changes to these efforts (as described in the plan) occur, the contractor must report and justify them to the SPO.

3.9.3 Basic Considerations

Previous sections of this guide indicated the importance of MIL-H-46855 to the accomplishment of the HE effort. It is the purpose of this section to briefly present basic considerations not covered in the MIL-H-46855 requirements or other data presented in Section 3.1. These considerations consist of the type of data required to start any HE effort, when to perform the effort, the level of detail required, and the type of specific results normally expected from the HE effort. Later paragraphs of this guide deal with these basic considerations in relation to specific HE techniques, but this paragraph pertains to these basic considerations in relation to the overall HE effort.

3.9.3.1 Data Inputs

There is a large variation in the degree to which data inputs such as mission requirements, system requirements, or operational concepts will be supplied by the customer or by contractor program organization other than HE. More often than not, mission analysis and functional flow diagrams are not provided to the HE group. The current tendency in industry is to have this type of information generated by HE. Other technologies such as software design and displays/controls provide data to HE as to the software and hardware capabilities and limitations. Data inputs pertaining to human performance and previous system experience have to come from research, literature, or from personnel experience. The specific data sources for these inputs are either too numerous or too intangible to list here. The data inputs for the later design and test phases of HE are obtained from HE analysis or from other technologies.

3.9.3.2 Timing

Without the proper scheduling of the HE analysis, design, and testing effort, it can turn out to be of little use to the system design. It is not sufficient just to perform these HE efforts. It is equally important to demonstrate that the results of the effort will be completed or partially completed at a point in the schedule when it can properly impact the system design. Occasionally, the HE efforts are performed on a portion of a program that later evolves to the point where the HE effort must be performed again to be pertinent. Sometimes the results of the effort are premature to their use by other technologies. However, all too often HE tasks are performed as an after-the-fact documentation exercise or just a workaround procedure that appears in a technical publication. The later the analysis, design, or test is performed, the less chance there is to impact the crew station or other man/machine interface. Late findings of serious crew system problems can be extremely expensive in redesign and in retraining, or worse yet, late inputs may be disregarded to the extent of causing serious system failures and accidents.

3.9.3.3 Level of Detail

Just as the HE effort may be performed too soon or too late, the analysis, design, or testing detail can be performed at too gross or too detailed a level. A discussion of the definition of various levels of analysis is contained in a later paragraph. The level of analytical detail that should be performed is significant to the HE manpower effort. Analysis must be performed judiciously to insure that proper emphasis is given to each of the various tasks or mission functions which are candidates for HE analysis. It is the job of the human engineer or HE manager to decide which level of analysis will lead to worthwhile data or useful design criteria. For example, new system designs or programs often contain functional requirements that are identical to previously designed and tested systems. There is no point in repeating a detailed analysis, design, or test that has already been accomplished. It is simply not cost effective, especially when new program schedules and manpower budgets generally are extremely limited.

The level of analytical detail achieved during functional allocation trades must suffice to permit positive allocation of functions to operators, equipment, or software. The functional allocation analyses have not been performed satisfactorily if the answers to the trades tend to come out as a combination of operator/equipment/software allocations. More detailed task analysis should be performed only on critical tasks or in accordance with required Data Item Descriptions. In similar manner for design, if other organizations have the charter to perform the detailed design of program hardware, it behooves HE personnel to provide little more than the HE design criteria. The details of the complete design, including specifications and drawings should not be performed by HE. On the other hand, HE personnel cannot offer just negative criticism of other organizations' designs. All criticism must include sufficient detail to let the designer know specifically what is wrong with the design and what could be done to modify it to meet proper HE design criteria. It is also the job of the HE T&E observer or manager to decide what level of T&E will lead to worthwhile data or useful design criteria. For example, there is no need to examine new system portions which are identical to satisfactory old systems. On new system designs, it may be necessary to examine data down to as much detail as a tenth of a second. If the HF program has been properly managed, all system potentially critical tasks will have been previously indicated for special HE T&E considerations. In any case, the need to gather human performance related T&E field data more accurately than a tenth of a second is extremely doubtful. In a similar manner, the HE observer should maintain adherence to the rules for significant figures and common sense when gathering data on light levels, sound levels, reach envelope measurements, etc.

3.9.3.4 Applications

The purpose of performing the three major HE activities (analysis, design and test) is to help develop and justify a system design. The purpose of doing HE analysis to successively detailed levels is to "drive out" or identify more and more significant detailed design requirements. Examples

of such data are: how many and what kinds of personnel will use the system; what the crew performance limits are in terms of time, space, force and reliability; and what the possible alternative solutions are. Design requirements are incorporated into mockups, drawings, and specifications. The end product of HE T&E is to verify system design, discover system inadequacies, and provide recommendations for design or other system changes. In addition, a by-product may be to provide information for a data bank of human performance and crew systems design related data to be used on later programs. Generally, the outputs of these efforts should be condensed and otherwise modified to make them more easily understood by the program personnel who have use of them and are not trained in HE techniques. Tables 3.9-1, -2 and -3 show most of the applications for data developed from using the various listed techniques.

It may be useful for the applications or specific output data to be prioritized in some manner to show that there are certain absolutely essential system HE design requirements or modifications which are necessary. The risk of not doing this is to have insignificant results acted upon and critical data ignored. All findings must be well documented and files must be maintained. By themselves, verbal inputs (HE outputs) as to analysis, design, or T&E results have virtually no chance of acceptance.

3.9.4 Analysis

In order to develop HE performance criteria and hardware HE design criteria and to accomplish the required analysis described in MIL-H-46855, a concerted analysis effort must be accomplished.

Initial development of man-machine interface concepts must be concurrent with advanced development of system concepts. During this formative period of system development, the human engineer has a number of important responsibilities:

Table 3.9-1. Human Engineering Analysis Techniques Data Applications

Specific HFE analysis techniques	Mission effectiveness criteria	Detailed design requirements	Concept formulation ideas	Personnel requirements information	Operational procedures development	Training system development	Maintenance system development	System operational evaluation	Additional human factors analysis	HFE data store information
1 Mission profiles	●		●						●	
2 Mission scenarios	●		●						●	
3 Functional flow diagrams		●	●		●	●	●		●	
4 Decision/action diagrams		●	●		●	●	●		●	
5 Action/information requirements		●	●						●	
6 Functional allocation trades		●	●			●	●		●	
7 Time lines	●	●	●	●	●	●	●	●	●	●
8 Flow process charts	●	●	●	●	●	●	●	●	●	
9 Operational sequence diagram	●	●	●	●	●	●	●	●	●	
10 Task descriptions	●	●		●	●	●	●	●	●	●
11 Workload analysis	●	●	●	●	●		●	●	●	●
12 Correlation matrix		●	●			●		●	●	
13 Link analysis		●	●		●		●	●	●	
14 CAFES FAM	●		●	●				●	●	●
15 CAFES WAM	●		●	●	●		●	●	●	●
16 SAINT	●	●		●	●	●	●	●	●	●
17 TLA-1	●	●	●	●				●	●	●

Table 3.9-2. Human Engineering Design Techniques Data Applications

Specific HFE design techniques/tools \ Applications	Concept formulation ideas	Detailed design requirements	Personnel requirements information	Operational procedures development	Training system development	Maintenance system development	System operational evaluation	Additional human factors analysis	HFE data store information
1 Design criteria checklist		●			●	●			
2 Drawings	●	●			●	●	●	●	●
3 Vision plots	●	●			●		●	●	●
4 Reach envelopes		●			●	●	●	●	●
5 Mockups	●	●	●	●	●	●	●	●	
6 Models		●	●	●	●	●	●	●	
7 Manikins		●				●	●	●	●
8 Specifications		●	●	●	●	●	●	●	
9 CAFES (CAD, CGE)		●					●	●	●
10 HECAD		●					●	●	●
11 COMBIMAN		●					●	●	●
12 CAPE		●						●	

Table 3.9-3. Human Engineering T&E Techniques Data Applications

Specific HFE T&E techniques/tools	Concept formulation ideas	Detailed design requirements	Personnel requirements information	Operational procedures development	Training system development	Maintenance system development	System operational evaluation	Additional human factors analysis	HFE data store information
1 Continuous observation	●	●	●	●	●	●	●	●	●
2 Sampled observation	●	●	●	●	●	●	●	●	●
3 Spec. comp. summary sheet		●				●	●		●
4 TO funct. evaluation				●		●	●	●	●
5 HFTEMAN		●				●	●		●
6 Env. and perf. meas. equipment	●	●					●		●
7 System records review			●	●	●	●	●	●	●
8 Test part. history record			●		●		●	●	●
9 Interviews	●	●	●	●	●	●	●	●	●
10 Questionnaires	●	●	●	●	●	●	●	●	●
11 Motion pictures	●	●	●	●	●	●	●	●	
12 Sound tapes	●	●	●	●	●	●	●	●	
13 Video tapes	●	●	●	●	●	●	●	●	
14 Photography	●	●	●	●	●	●	●		
15 Event recording	●					●	●	●	●
16 Secondary task mon.	●		●				●	●	●
17 Physiological instrumentation	●						●		●
18 Physical measurement	●		●				●	●	●
19 Online interactive	●		●	●	●			●	●
20 Statistical analysis		●	●				●		●

a) Assurance that human engineering inputs are incorporated into system design requirements documentation;
b) Major participation in the allocation of system functions to man, machine, or software, or combinations thereof;
c) Assurance that each candidate system functional implementation is feasible in all respects from a human engineering standpoint;
d) Development of design concepts for each operator/maintainer work station to the point that it is reasonably assured such a work station arrangement is operable;
e) Performance and documentation of preliminary hardware trade studies pertaining to human engineering considerations;
f) Identification of potential human engineering problem areas which may require attention;
g) Preparation of inputs to subcontractor RFP packages as applicable.

These tasks are frequently accomplished by the analysis process of breaking them down into smaller and smaller elements to the point where they can be handled. At the smaller element level, significant aspects of the total problem can be examined in detail. Answers to several detailed questions/problems are more easily obtained than answers to a few top level question/problems.

Generally, the analysis process starts with the system mission as described by a baseline scenario. The mission objective and functions that must be performed by the system are identified, described, and sequenced. These functions are then analyzed to determine their proper allocation to personnel, software, or equipment, or some combination of these. Once allocated, the personnel functions are further analyzed to determine the specific operator/maintainer tasks which must be performed to accomplish the functions. The tasks are further detailed to show estimated time and space relationships.

Over the years, human engineers have developed a number of powerful tools and techniques to aid in applied human engineering work. Each of the following subparagraphs describes the characteristics of one technique. Information is supplied as to what the technique is, what it is intended to do, and why it is useful. Much of this information is presented in tabular form in Table 3.9-4. By listing each of the techniques on one table, they may be more easily compared for selection and use. An explanation of each of the table Selection Evaluation Characteristics is provided in Table 3.9-5. Procedures for the construction of each technique are provided. When significant, the limitations as to what the technique will not do are pointed out. Also included are sample formats to illustrate the layout and details of several of the techniques.

This guide contains only the better known techniques. Reference 11 (Geer, 1976) contains data on a few additional techniques. If for some reason it is felt tnat existing techniques will not accomplish the required analysis task, then obviously new techniques should be developed. The development of new paper and pencil analysis techniques is generally not difficult. The major drawback in doing this is the extra educational process that is required to assist those wishing to understand, review, or otherwise use the analysis.

3.9.4.1 Mission Profiles

Description: Mission analysis is the first step in the system development required for the establishment of human factors design criteria. The system mission or operational requirements are a composite of requirements starting with general operational requirements and progressing through specific operational requirements. The mission requirements define the system in terms of limits of operation necessary for fulfilling the weapons system mission activities. Mission profiles, along with scenarios, are the two major techniques used to perform mission or operations analysis. The total analysis process must start with mission profiles

Table 3.9-4. Analysis Techniques Selection Chart

Alternative analysis techniques	Most applicable program phase				Relative complexity			Used for		Breadth		Relative time to perform			Used by		Relative cost (~man-years)			Relative cost effectiveness		
	Conceptual	Validation	FSD	Production	Simple	Average	Complex	Gross analysis	Detailed analysis	Single task	Simultaneous tasks	Short	Medium	Long	Managers	Analysts	Low	Medium	High	Low	Medium	High
1 Mission profiles	X				X			X		X		X			X	X	X					X
2 Mission scenarios	X				X			X		X	X		X	X	X	X		X			X	
3 Functional flow diagrams	X	X			X			X			X	X	X		X	X	X	X			X	X
4 Decision/action diagram	X	X			X	X		X			X	X	X			X	X	X				X
5 Action/information requirements	X	X				X			X	X			X			X		X			X	
6 Function allocation trades	X	X				X		X	X		X	X	X		X	X		X			X	
7 Time lines	X	X				X		X	X	X	X	X			X	X		X				X
8 Flow-process charts	X	X				X			X	X			X			X		X			X	
9 Operational sequence diagram	X	X					X		X		X			X		X			X		X	
10 Task descriptions	X	X	X		X			X	X	X			X		X	X		X		X	X	
11 Workload analysis		X	X	X		X		X	X	X	X		X			X		X			X	
12 Correlation matrix	X	X			X				X		X	X			X	X	X					X
13 Link analysis	X	X	X			X			X		X		X			X		X			X	X
14 CAFES (FAM, WAM)	X	X					X		X		X			X		X			X		X	
15 SAINT	X	X					X		X		X			X		X			X		X	
16 TLA-1	X	X					X		X		X			X		X			X		X	

Selection evaluation characteristics

Table 3.9-5: Explanation of Selection Evaluation Characteristics

Across the top of Table 3.9-4, Analysis Techniques Selection Chart, are a number of selection evaluation characteristics. The purpose of this characteristics list is to make evaluative comments as a part of a tradeoff analysis between the various listed analysis techniques. Some techniques are obviously better than others for certain types of programs, program stages, or analysis efforts. The following list describes in detail what is meant by each of the evaluation characteristics.

DEFINITION OF TECHNIQUES SELECTION EVALUATION CHARACTERISTICS

MOST APPLICABLE PROGRAM STAGE

The phase of a program that is best suited to the use of this technique: Conceptual Phase, Validation Phase, Full-Scale Development Phase, and Production Phase (Ref. AFM 11-1), (See Table 3.4-1).

RELATIVE COMPLEXITY

The category of relative complexity that best describes this technique when compared to other techniques.

USED FOR

The category that best describes the level of detailed analysis for which this technique may be used.

BREADTH

Indicates the relative quantity of different tasks that may be simultaneously handled by using this analysis technique.

RELATIVE TIME TO PERFORM

The time category that best describes the time to perform this technique for a given task, when compared to other techniques.

USED BY

The types of users of the analysis technique, either or both.

RELATIVE COST

The category that best describes the relative cost of this technique when compared to other techniques.

RELATIVE COST EFFECTIVENESS

The category that best indicates how effective this technique is when compared with other techniques.

because the human factors engineer must have a good idea of the operational situation or events that will be confronting operators and maintenance personnel in newly conceived systems. Although historically mission analysis has been performed by groups other than human factors, the trend has been either to cut down on the size of the System Engineering or Operations Analysis groups who have done this work, or to eliminate the groups altogether in the name of cost savings. However, the need for the analysis is as critical as ever and the work must therefore be performed by someone, such as a human factors engineer.

Procedure: The procedure for constructing mission profiles is easy to follow. The term mission profile derives its name from the typical side view format illustrated in Figure 3.9-1. The profile is a plot of the aircraft flight in terms of total distance traveled (or time) from home base. Significant mission events or functions are noted on the plot. Mission "profiles" other than the illustrated example are also used to indicate the flight path in terms of latitude and longitude such as would be observed in a plan view in a manner similar to a horizontal situation display. These particular plots are often referred to as graphic scenarios. Significant aircraft functions are plotted along the route at the points of their planned occurrence. Each function describes a clearly distinguishable start and completion point for a mission segment.

Use/Validity: Along with the initiation of new programs, there is invariably the issuance of top level program objectives and systems operational requirements. It is a combination of these objectives and requirements with the past experience of previous similar systems which combine to create the mission profile data. If all essential operational

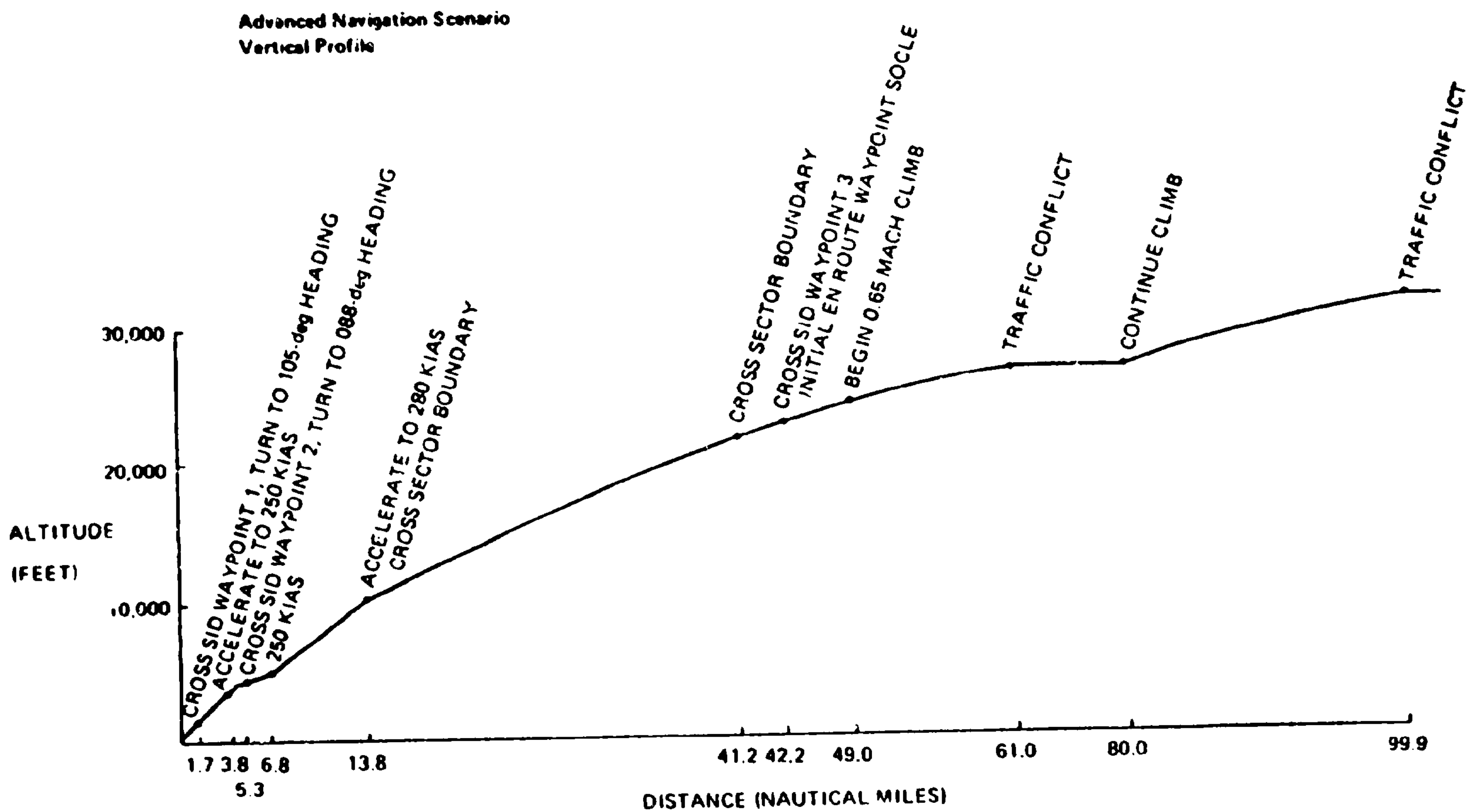


Figure 3.9-1. Sample Mission Profile

requirements cannot be logically and realistically included into one profile, then others must be developed to cover all functions in a reasonable context. Although mission scenarios are sometimes developed before mission profiles, they generally follow the profiles and use the mission profile functions to interact with scenario threat and other event data. In addition to feeding into the scenarios, the mission profile data are used in the development of the functional flows. Table 3.9-1 illustrates several output applications that apply to mission profiles.

The inherent characteristics of the mission profile analysis technique when compared to other human factors engineering techniques are summarized in Table 3.9-4. Mission profiles should be developed as early as possible in the program schedule. Given any sort of basic system requirements to build on, they may be simple to construct. However, if numerous threats/events are used, they become much more complex. They are generally used for a gross analysis only. At any one point in time, they may be used to show single top level tasks better than several simultaneous tasks. Mission profiles require a minimum of time to develop. They are used equally by managers and analysts. Their cost is low and their cost effectiveness relatively high.

3.9.4.3 Mission Scenarios

Description: Scenarios are developed from the threat/concept and the mission profiles, and they must fully describe the events implied by the profile. Rather than using a special format for scenarios, they are generally written in straightforward narrative. This narrative should describe the proposed mission in detail, identifying key events and implied requirements that might otherwise be overlooked.

This includes all essential system functions, such as failure modes or emergency procedures. Elements of the scenario should be sufficiently detailed to convey an understanding of the mission, and to permit a breakout of mission variations relating to features such as a) mission phases, b) the activity performed in each phase, c) the approximate degree of accuracy for each activity, and d) any interdependencies of activities as to timing, information transfer, etc.

Procedure: There are no precise rules for writing scenarios; however, there are a number of factors that should be considered for inclusion in them. These factors are:

a) Assumed operational tactics.
b) A listing of subsystems and their proposed capabilities (e.g., sensor range, navigation accuracy, etc.)
c) Postulation of a geographic position - this would include boundaries and terrain elevations.
d) A selected starting point in terms of time and location.
e) Placement of both threats and unknowns within the geographic area.
f) Adherence to the previously developed mission profile(s) in terms, routes, and distance.
g) Development of limited profiles for each of the unknown and hostile tracks (contacts).
h) Determination of the location of stationary threats/targets.
i) Based on subsystem capabilities, determination of when sensors are active and what their capabilities are as to target/threat detection.
j) Development of target identification techniques.

k) Utilization of all significant system capabilities.

l) Development of hostile target nullification techniques.

m) Completion of the scenario until the threats are destroyed or the system capabilities are depleted or successfully countered.

The scenario should identify which tactics appear to be feasible, which may overstress the system, and which mission functions must be broken down to lower, more detailed levels in order to determine their feasibility and operation within the context of the scenario. If possible, the user command should be contacted to obtain information to assist the development of the scenarios.

Use/Validity: All of these data wil be used while performing the various analysis techniques such as functional flows, decision/action diagrams, and/or action/information requirements. Table 3.9-1 indicates the output applications, including mission effectiveness criteria, which result from performing mission scenarios.

Mission scenarios are compared to other analysis techniques in Table 3.9-4. Review of the table indicates that the scenarios should be developed early in the program. They are simple to perform because no elaborate symbology or functional links are required. They are used for gross analysis more than for detailed analysis. Tasks may be described for single operator systems or multioperator systems. Mission scenarios may take a long time to develop if the proposed system is relatively new and unique. Additional time may be required to detail new data for subsystem capabilities. The scenarios will be used by managers as well as analysts. Their relative cost and cost effectiveness may be rated as average.

3.9.4.3 Functional Flow Diagrams

Description: Functional flow diagrams are the most popular systems technique used for the determination of system requirements. Starting with system or mission objectives, functional flows are developed iteratively for more and more detailed system requirements down to the level of specific operator tasks. Functional flow diagrams can provide a detailed outline of all system requirements. They may be used as an extensive checklist of system functions that must be considered in assuring the ability of the system to perform the mission. This analysis of system functions is required to determine solutions for later trade studies. Functional flows are necessary to determine effectively which system functional elements should be performed by operators, equipment, software or some combination of these. In general, during the construction of higher level flows, no distinction should be made between operator, equipment, or software implementation of system functions. The lack of distinction is for the purpose of conducting unbiased system trade studies.

Functional flow diagrams are often referred to as functional block diagrams, functional flows, or functional flow block diagrams. All of these terms refer to the same analysis technique. It has undoubtedly evolved from the use of schematic block diagrams that depict the relationships between various equipment items in a system. The major difference between the schematic diagram and the functional flow is the addition of the verb to the noun label in each schematic block. By the use of verb-noun functions, the system is prevented from becoming prematurely committed to an arbitrary design implementation solution. A function may be defined as a verb-noun phrase that must be accomplished by a system. All functions can be broken down or divided into more detailed functions.

Procedure: Sample functional flows are shown in Figure 3.9-2. These flows are constructed by arranging in system sequential order all of the various functions that are believed to pertain to a particular system (or subsystem, depending on level of detail). Each function is a verb-noun combination. Occasionally nouns are assumed and adjectives are added. Each individual function is contained within a rectangular block. Each block is numbered for reference more or less according to its sequence on the page. These numbers remain with the function as long as the function is unique.

If the function is repeated in other portions of the total series of functional flows, the same number should be used and the block may be drawn as a reference block. Each functional flow diagram contains a reference to its next higher functional flow through the use of a reference block. Reference blocks may also be used to indicate functions occurring at the same level on different pages. The blocks in Figure 3.9-2 that are broken in the middle are reference blocks. The numbers are important to insure traceability either back to the higher level functions or between functions.

The functional flow symbology used in Figure 3.9-2 is typical. The direction between the function blocks indicates the normal sequence of occurrence of system functions. Contrary to the ground rules for constructing schematics, the arrows between functional flow blocks should show the general flow of the diagram toward the right and, if necessary, down. Arrows should not be used on either the top or bottom of the blocks. They should enter the block from the left and exit to the right.

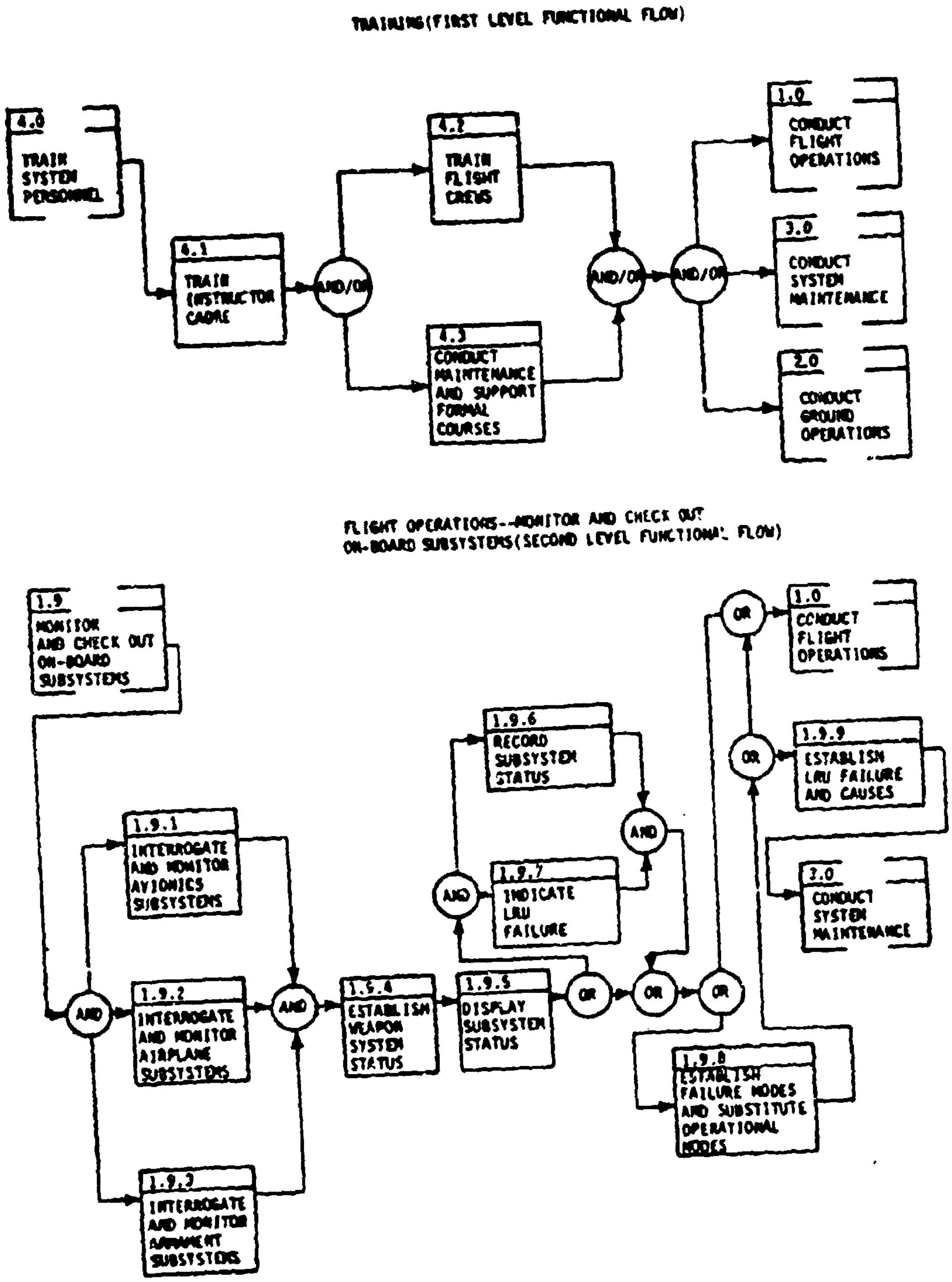


FIGURE 3.9-2: SAMPLE FUNCTIONAL FLOW DIAGRAMS

Wherever arrows are joined or split out, they should be connected by an "and", "or", or "and/or" gates or junctions as indicated in the sample. The significance of the "and" junction is that all of the following or preceding functions must be performed. The "or" junction indicates a choice between two or more of the following or preceding functions as to which one is performed. The "and" and "or" junctions may be combined if it will not cause confusion and page space is limited.

In addition to the previous discussion, the point should be made that a function is that which must be accomplished by the system and that all functions can be broken down or divided into more detailed functions. Top level and first level functions tend to be identical for similar systems (e.g., perform: preflight, taxi, takeoff, etc.). A specific operational requirement may call for modification to these higher level functions; however, the changes generally occur to the lower level functions. For large programs, such as a complete air vehicle system, they are gross system operations. The second level functions would then tend to describe system operational (or maintenance) functions within the various mission phases. The third level may define specific functions with measurable performance units. Functional allocation between operators, equipment and software may occur at this level. Fourth level functions may be the level at which gross operator task analysis may occur. The total concept of functional level detail or definition must be based on the total size or scope of the particular system to be analyzed. Naturally, the smaller the system being worked, the more detailed the corresponding numerical level of functional analysis will be. Larger systems or programs will require more levels to get to the same degree of detail.

In view of this possible ambiguity as to functional level definition versus program scope, it is recommended that all parties concerned (e.g., customer and contractor) agree on the definitions before considerable effort is expended on this or similar techniques. The definition of functional levels is not as important as the assurance that analysis is conducted to a sufficient degree of detail to determine significant operator performance requirements, particularly the details of critical operator tasks. The reference number groups recommended for use with each of the levels is as follows: 1.0, 2.0, 3.0, etc., for top level functions: 1.1, 1.2, 1.3, etc., for first level functions: 1.1.1, 1.1.2, 2.1.1, etc., for second level functions; and 1.1.1.1, 1.1.1.2, 2.1.1.1, etc., for third level functions and so on.

Once the functional flows are constructed, the functions and subfunctions should be reviewed and analyzed in depth for probable variations related to the system requirements. Even during early development, both alternative mission requirements and the expected downstream developmental impact of such alternatives should be appraised to produce an early estimate of likely crew interface requirements, capability, special provisions needed, potential problems and probable solutions.

In come cases, the analyst may also need to produce preliminary workload data and to provide information for manning and training estimates. In any case, he must anticipate a wide variety of possible requirements to form a judgment for both crew performance feasibility, support requirements and development needs.

Some of the essential features to remember about the procedure for constructing functional flows are as follows:

a) Functional flow blocks must contain a verb and a noun.

b) It is essential to initiate the flows on a system framework and without any allocation to operator, equipment, or software.

c) Each expanded level of functional flow will contain more and more detailed information. The detail may be carried on to as many levels as appropriate. It is normally necessary to go to at least the third level.

d) Functions are numbered in a manner which preserves continuity of function and logical breakout from function origin.

e) The diagram should be organized so that one can easily find the input and follow the flow through the function blocks to the resulting output.

f) It is generally good practice to limit the size of the diagrams. They should be divided up if too large for foldout pages in documents. Reference blocks may be used. If designed for display on walls, the functional flows may be of relatively large size.

Use/Validity: Functional flow diagrams are extremely useful to the human factors engineer for a number of reasons. The functional block numbering system provides a rationalized traceability from lower to higher level functions and between functions at the same level. Functional flows are flexible in that a change in one part of a total functional flow generally causes minimal effect on other parts. Because of this, they are easy to use to show the effects of preliminary functional allocation trades to man, machine or software.

Because of this flexibility and ease of use, they are an ideal technique to use for the rapid analysis of system functions proposed by other program personnel such as subsystem designers. Functional flows are the ideal way to show the relationships between functions. They may be constructed in such a manner as to show as many as forty or fifty different functions on one foldout page. If wall space is available, complete systems or subsystems may be laid out, depending on the level of detail desired. Functional flows are relatively easy to develop. Whereas some human factors engineering analysis techniques require special training prior to their use, the functional flow diagram requires only minimal training. The functional flow diagrams are also a relatively fast analysis technique and accordingly, they tend to be very cost effective. The only reason for not using this analysis technique would be to use another technique in its place, such as the decision/action diagram, (discussed in next paragraph, 3.9.4.4), which incorporates most of the same features of the functional flow. Functional flows do not contain information pertaining to decisions and time-based information flow, although functional flows tend to be time sequential. Functional flows generally do not indicate operator, equipment, or software allocations, except at a lower, more detailed level.

The data for the functional flows originally come from the mission profiles and scenarios that are developed during the operations analysis program effort. Data for more detailed lower level functional flows also come directly from the higher level flow diagrams and from the subsystem design groups. In a similar manner to all other analysis techniques, the functional flow diagrams are not an end in themselves. There is little or no point in constructing them if they are to be completed only to be filed away.

As more and more detailed functional flows are developed, specific system requirements begin to emerge. These requirements may then be documented by incorporation into system specifications. As previously indicated, functional flows are used to assist in the performance of functional trades (i.e., trades performed to choose between or among two or more functional alternatives). The results of the trades should evolve into detailed system requirements or specifications. The functional flows are seldom adequate to develop detailed system requirements where operators are involved. Additional analysis techniques such as time lines, requirements allocation sheets, and/or operational sequence diagrams need to be generated to develop system requirements pertaining to system decision functions or time constraints.

Review of Table 3.9-1 indicates several specific output applications that result from performing functional flow analysis. Table 3.9-4 indicates numerous evaluation characteristics of the functional flow as compared to other analysis techniques. The technique is best used during concept formulation and after DSARC I phases of the program. It is relatively simple to perform this technique at a gross function level. As more detail is required, other techniques should be selected. It is best suited to gross analysis. Analysis of several simultaneous functions is no problem to perform with functional flows. The time to perform functional flows is relatively short; but that is, of course, a function of the total analysis effort involved. Functional flows may be expected to be used by both managers and analysts. Their relative cost to perform is from low to medium and their relative cost effectiveness is from medium to high.

In summary, functional flows provide a detailed and comprehensive inventory of all system requirements and an extensive checklist of system functions and factors that must be considered in assuring ability to perform the mission. Properly structured, the inventory will proceed from functional indentures common to all similar systems (e.g., aircraft), through indentures peculiar to an aircraft type (e.g., fighters) and on to functional elements that are specific to mission operations. Detailed analysis of the functions is required to determine basic methods of achievement, possible equipments, and man/equipment trades in order to effectively determine which elements should be performed by equipment and which should be performed by man.

3.9.4.4 Decision/Action Diagrams

Description: The decision/action diagram is a technique similar to functional flows. It is used to show the flow of required system data, in terms of operations and decisions. Like functional flow block diagrams, decision/action diagrams may be developed and used at various levels of detail. The initial decision/action diagram charts are concerned with gross functions without regard to whether functions are performed by man, machine, software, or some combination of these. The decision/action diagrams prepared subsequent to tentative man-machine-software function allocations will reflect this allocation in the decisions, operations, and branching which are represented. At the program concept formulation stage, however, these charts would ordinarily be prepared at a detailed level only for the more critical man-machine functions.

This technique may also be referred to as information flow charts, decision logic diagrams, or operation/decision diagrams. The term, information flow charts, generally refers to a type of decision/action diagram that has a vertical orientation on the page rather than the left to right horizontal orientation that decision/action diagrams use. Special symbology may also be used with the information flow charts at a more detailed level to indicate allocations to man or machine (e.g., single line symbols mean manual, double line mean automatic).

The decision/action diagrams are so similar to functional flow diagrams that the use of both techniques is not recommended. The most significant difference between the two techniques is the addition of the decision blocks (diamonds) to the functional flow diagrams. The decision/action diagrams are generally used when the program is software oriented.

In that it records the sequence of operations and decisions which must be performed to satisfy a definite system function, the decision/action diagram is similar to the flow charts used by computer programmers. Both charts are based on binary choice decisions and intervening operations. There are two important reasons for using binary decision logic as a standard in performing decision/action diagramming:

a) To expedite communications through use of simple yet universally appicable conventions.

b) To provide for easy translation of decision/action flow charts into logic flow charts for computerized sections of the system.

A decision at a general level may split into several decisions at a more detailed level, for example:

General level: - Do any targets need identification processing?

More specific level: - Do any newly entered targets need identification processing?

- Do any target tracks need confirmation of tentative identification?
- Do any confirmed identifications need rechecking?

Each of these more detailed decisions may have associated with it one or more detailed operations. Similarly, an operation at a general level may break down into more detailed decisions and operations.

The example in Figure 3.9-3 is a gross level detection and tracking function. No functional allocation has been made to man or machine. Note that at this level the chart is applicable to several detection and tracking systems - the decisions and operations are essentially common between them. Even here, however, the usefulness of the flow chart diagramming technique is apparent because it makes the analyst begin to consider implementation alternatives, such as:

a) By what means can any given signal be compared with known targets in the system?

b) How can probable targets be marked so their reappearance can be readily recognized?

The information necessary for the initiation of decision/logic diagrams comes from the mission profiles and scenarios. Data for more detailed lower level decision/logic diagrams may come directly from higher level flow diagrams and from sybsystem design groups as equipment detailed characteristics become well defined.

Procedure: The procedure for constructing decision/action diagrams is essentially the same as that for functional flow diagrams. They are constructed by arranging in sequential order all of the functions and decisions that pertain to a system or subsystem (depending on level of detail). Each function is a verb-noun combination with occasional adjectives or other modifiers. Each function phrase is relatively short and is contained within a rectangular block. Each decision function is placed in a diamond shaped outline symbol and is written in a question format that may be answered with a binary, yes-no, response. Both the functional action blocks and the decision diamonds should be given reference numbers in a manner similar to the numbers assigned to functional flow diagrams.

The numbers are important to ensure traceability between decision/action blocks. The decision diamond blocks may be drawn in solid or dashed lines to indicate primary decision functions or shared decision functions, respectively. The use of arrows between function/decision blocks is similar to functional flows. Note that flow paths should be complete. Every path should either recirculate or end in a valid exit with a reference block. The junction between arrows are handled with "and", "or", or "and/or" gates in the same manner as with functional flows. (Reference paragraph on Functional Flow Diagrams, Procedures).

GROSS DETECTION AND TRACKING FUNCTION

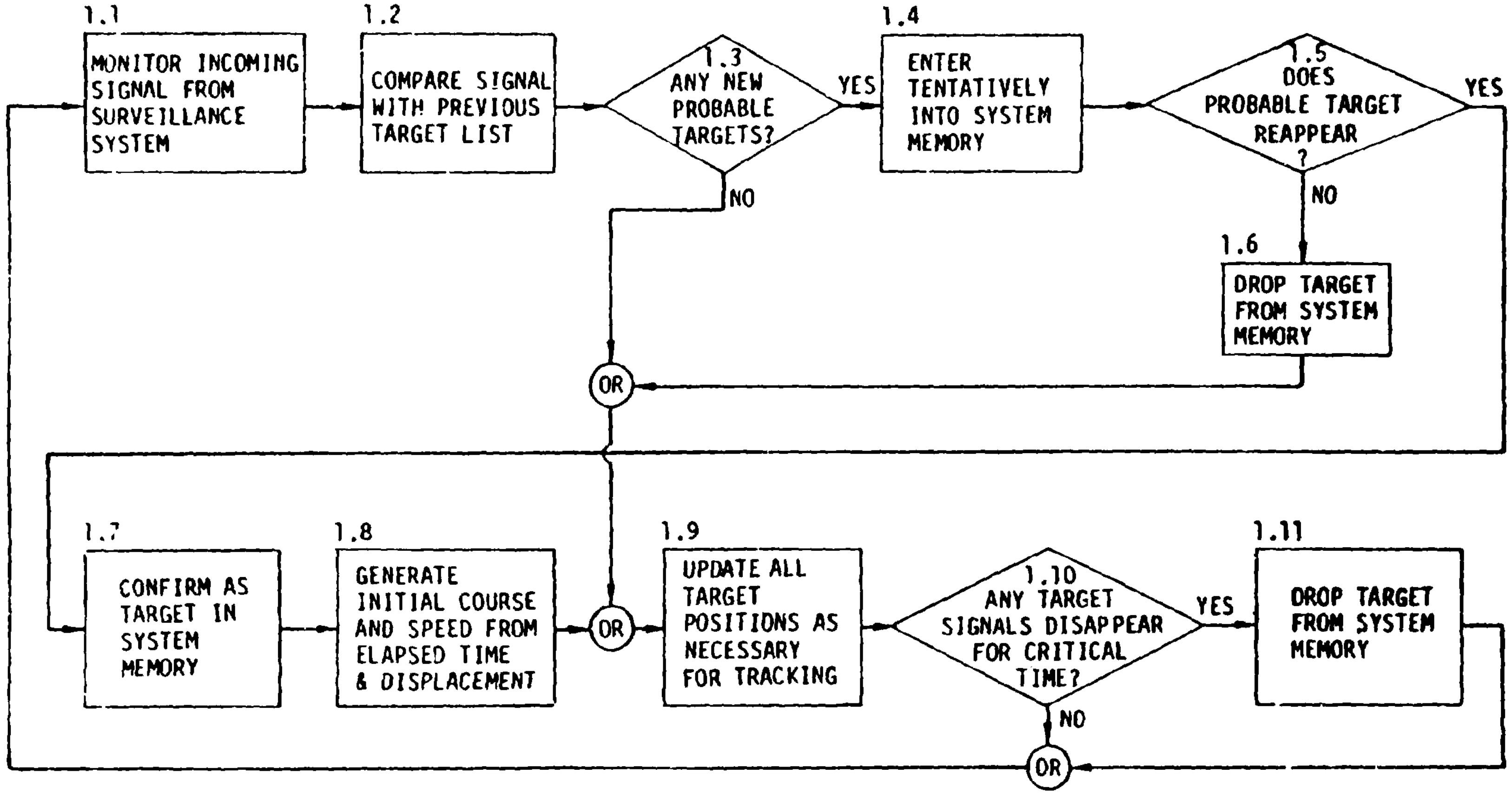


Figure 3.9-3: Sample Decision/Action Diagram

Use/Validity: The results of the decision/action diagram analysis are used to develop specific system requirements and assist in the performance of trade studies. Additional analysis techniques such as time lines are almost always needed following the construction of the decision/action diagrams in order to investigate the effect of the critical system parameter, time. Worthwhile computer simulations have been successfully performed with the addition of time data to detailed decision/action diagrams that include preliminary allocations of functions to operators. Table 3.9-1 indicates several specific output applications that result from performing decision/action diagrams. The technique is well suited to initial development of software programs in general, and display software in particular.

Review of Table 3.9-4 indicates a preference for performing decision/action diagrams during the earliest phase of a program. They are considered to be either average or simpler than average in complexity, but they must still be considered slightly more complex than functional flows because of the added decision functions. They are better used for gross analysis and may be used to analyze several simultaneous functions. They require a relatively short to medium time to perform and cost an average (or less) amount of manpower effort. They rate higher than average in cost effectiveness. The decision/action diagrams are useful to both analyst for the determination of detailed system requirements, and to HFE managers for the determination of more general program or system requirements.

3.9.4.5 Action/Information Requirements

Description: Given the functional flows, or decision/action diagrams, analytic procedures for performing preliminary functional allocation are somewhat dependent on the analyst and his objectives. For the purpose of performing functional allocation trades, one alternative technique is to make the allocation from the level of the detail provided in the functional flows. However, experience suggests that more detail than that provided at the functional level may be desirable before making allocation trades. A format which has been useful in producing this detail in an appropriate context is the system "action/information requirements". Figure 3.9-4 illustrates such a form. Use of this format helps in defining those specific actions necessary to perform a function and, in turn, those specific information elements that must be provided to perform the action. It breaks up the referenced "functional requirement" into useful groupings of "action requirements" and "information requirements". This particular sample format is expanded to include detailed aspects of the function such as related information requirements, sources, and problems. Related accident features and survey commentary are also included in this example. However, the precise format of this particular form does not need to be rigidly controlled.

Procedure: The procedure for developing or completing action/information requirements forms is much more informal than that for most analysis techniques. Often the three columns illustrated on the left side of the form illustrated in Figure 3.9-4 are all that are used. The first column is used to list the function and function number from the functional flow diagrams. The second column is used to list each of the action requirements indicated by the function. The third column is used to list the information

APPROACH REQUIREMENTS ANALYSIS			TRADE-OFF INFORMATION AND DATA INTEGRATION		
APPROACH-LAND FUNCTIONAL REQUIREMENTS	ACTION REQUIREMENTS	INFORMATION REQUIREMENTS	RELATED INFORMATION REQMT'S/ SOURCES/PROBLEMS	RELATED ACCIDENT FEATURES	RELATED SURVEY COMMENTARY
1.0 INITIATE PRE-APPROACH PROCEDURES	1.0.1 REVIEW APPROACH INFORMATION	1.0.1.1 APPROACH ORIENTATION 1.0.1.2 APPROACH CONSTRAINTS o APPROACH o REQMT'S o OBSTACLES o HAZARDS o WEATHER o MINIMA	APPROACH PLATE DATA o OBSTACLE LOCATIONS o COURSE/PATH DATA o TERRAIN CHARACTERISTICS o HAZARDS o MINIMUM DECISION ALTITUDES POSITION DATA	DATA MISINTERPRETED/ NOT USED EFFECTIVELY. HAZARDS MIS-APPRAISED. NAVIGATION POSITIONING ERRORS	o CAN'T REMEMBER ALL DETAILS o STUDY TIME IS LIMITED WHILE SETTING UP APPROACH o IMPROVE TO EMPHASIZE BASIC DATA-CRITICAL DATA BOLDER, E.G., GO-AROUND HDG./ALT. o NEED CLEARER PICTURE OF POSITION SITUATION
	1.0.2 COORDINATE APPROACH WITH CONTROL	1.0.2.1 COMMUNICATION o PATH DESIGNATION o UNIQUE LIMITATIONS/CONSTRAINTS o ENVIRONMENTAL CONDITIONS o BAROMETRIC PRESSURE	COORDINATION AND CONFIRMATION OF APPROACH CLEARANCE ALTIMETER SETTING	CLEARANCES/PROCEDURES ARE MISUNDERSTOOD/NOT FOLLOWED/ IN ERROR. ALTIMETER MISSET/ MISREAD. CONFUSION OF o INCHES MERCURY VS MILLIBARS o SEA LEVEL VS FIELD ELEVATION REFERENCE	o NEED PROCEDURES FOR BETTER COORDINATION BETWEEN AIRPLANE AND TRAFFIC CONTROL TO IMPROVE UNDERSTANDING OF SITUATION/ CONTROL INTENT o IMPROVE ALTIMETRY PRESENTATION METHOD o STANDARDIZE SETTING REFERENCES - FIELD ELEVATION PREFERRED FOR LANDING o REDUNDANT SETTING CHECKS o RADIO CHATTER/CHANGES

Figure 3.9-4: Sample Action/Information Requirements Form

requirements that come from the listed function. If more detail is desired for the preparation of the allocation trades, additional columns may be added on the right side of the form. In the example in Figure 3.9-4, related information requirements, sources, and problems are listed. A second column lists related accident features and the third column lists any other commentary. In this case, the column is used for survey results pertinent to the function being scrutinized. Additional data could be listed, such as the capabilities of operators or equipment for handling these functional requirements.

Use/Validity: Table 3.9-4 compares the use of this analysis technique to other techniques. The action/information requirements forms should be used after the functional flows but before the functional allocation trades. The appropriate time during the program to perform this analysis technique would therefore be during the concept formulation or after DSARC I. The technique is of average complexity. It is used at analysis levels sufficiently detailed to perform functional allocations. It is used to analyze one function at a time. It requires an average amount of time to perform and is of much more use to analysts than to managers. Its relative cost and cost effectiveness to perform are average. It is not recommended if there is relatively little difficulty in obtaining sufficiently detailed functions from which functional allocation trades may be performed.

Use of this particular technique provides the analyst with the information to exercise several options: a) he can identify equipment which satisfies the system requirements, b) he can perform associated man/equipment capability

trades for preliminary functions allocation, c) he can integrate similar or correlated system/action/information requirements to develop new concepts, or d) he can easily pair action requirements with possible control hardware and information requirements with possible display hardware.

The information used to construct these forms comes primarily from the functional flows. Additional data may be obtained from subsystem design engineers. The results obtainable from this analysis technique are used by human factors engineers in the performance of functional allocation trades.

3.9.4.6 Function Allocation Trades

Description: With the completion of the functional flow diagrams, decision/action diagrams, and/or action/information requirements, it is appropriate to perform preliminary trade-off studies of man-machine allocations for each of the functions being considered. Too often the allocations are based only on past experience, or worse yet, the allocations are simply arbitrary. A rationalized choice of functions is necessary for optimum system design.

These man-machine allocations provide the baseline for down-stream efforts relating to crew task definition, control/display operations requirements, crew station configuration concepts, workload evaluation and crew station design, development and evaluation. Additionally, function allocations dictate crew workload and significantly affect manning, training and procedures requirements. Early appraisals of the allocation impact on these requirements are necessary as part of the initial human engineering review process. Early appraisals that anticipate program and operational requirements are reflected in the earliest system development phases.

Working in conjunction with project subsystem designers (perhaps as a team to do this task) and using the functional flows, etc., plus their past experience with similar systems, the human factors engineer makes a preliminary allocation of the actions, decisions, and/or functions shown in the previously used charts and diagrams to operators, equipment, or software. The assignment of the functions, actions, and/or decisions to operators, equipment, or software must be based on: a) the known capabilities and limitations of operators, b) the state-of-the-art performance of hardware and software, and c) estimated performance to be required in terms of speed, accuracy, and load. The need for a cooperative effort between subsystem designers and human factors engineers at this point is extremely important. Each must contribute to make the allocations meaningful.

There are three specific techniques recommended to perform the details of the function allocation trade. The first technique is simply that of "trial and error" substitution of each of the alternatives into a system or subsystem model. Each alternative is then evaluated on a basis of total system or subsystem reliability or speed. This technique has some obvious drawbacks. It is not recommended for a systems analysis where a large number of functions need to be allocated. The technique lends itself for use to computer analysis much better than manual (paper and pencil) analysis. Computer-aided techniques that may be used for this type of analysis are described in following paragraphs of this guide.

The second technique is based on an evaluation matrix (Figure 3.9-5). Candidate subsystem functions are listed and compared against the "Fitts List" (Ref. 5, AFSC DH 1-3) man-machine capabilities (see Table 3.9-6). The form used

HYPOTHETICAL TRACKING FUNCTIONS	INHERENT OPERATOR CAPABILITIES					INHERENT EQUIPMENT CAPABILITIES			TOTAL SCORE		PROPOSED ALLOCATION			
	DETECTING SIGNALS IN THE PRESENCE OF HIGH NOISE ENVIRONMENT (X5)	RECOGNIZING OBJECTS UNDER VARYING CONDITIONS OF PERCEPTION (X4)	HANDLING UNEXPECTED OCCURRENCES OR LOW-PROBABILITY EVENTS (X4)	REASONING INDUCTIVELY (X1)	PROFITING FROM EXPERIENCE (X2)	RESPONDING QUICKLY TO SIGNALS (X3)	PERFORMING PRECISE ROUTINE REPETITIVE OPERATIONS (X2)	COMPUTING AND HANDLING LARGE AMOUNTS OF STORED INFORMATION QUICKLY AND ACCURATELY (X4)	OPERATOR	MACHINE	OPERATOR	BOTH	MACHINE: EQUIPM'T	MACHINE: SOFTWARE
1. DETERMINE IF TARGET TRACKS IN SYSTEM	25	8	12	3	6	9	8	4	81	41	X			
2. ACTUATE SEQUENCE	5	4	4	1	2	3	2	4	20	24		X		
3. PUT NEXT TARGET IN TRACK LIST UNDER CLOSE CONTROL	5	4	4	1	2	9	10	4	21	43			X	X
4. ADVANCE HOOK ON DISPLAY TO TRACK COORDINATES	5	4	4	1	4	9	10	4	21	43			X	X
5. DETERMINE IF TARGET VIDEO PRESENT	20	8	8	3	4	9	8	4	70	39	X			
6. DETERMINE IF HOOK LINES UP WITH PRESENT TARGET POSITION	20	8	8	3	6		8	4	73	40	X			
ETC....														

Figure 3.9-5: Sample Functional Allocation Screening Worksheet (Evaluation Matrix)

Table 3.9-6: Man/Machine Capabilities Fitts List

MAN EXCELS IN	MACHINES EXCEL IN
Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Detecting signals in high noise levels	Exerting great force, smoothly and with precision
Ability to store large amounts of information for long periods - and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time-periods
Ability to exercise judgment where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improvising and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infra-red, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in solving problems: i.e., alternative solutions	Deductive processes
Ability to profit from experi-ience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipula-tion, expecially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and pre-cisely the same way over a long period
Ability to continue to perform when overloaded	Operating in environments which are hostile to man or beyond human tolerance
Ability to reason inductively	

Reference AFSC DH 1-3

to perform this technique is called a functional allocation screening worksheet. Plausible operator roles or equipment functions (e.g., operating, monitoring, maintaining, programming, communicating, etc.) are identified using the screening worksheet. By comparing the functions to be performed with the inherent capabilities of man or machine to accomplish the functions, operator and equipment tasks are allocated. The comparison is evaluated and, based on the analyst's judgment, a weighted numerical score is assigned to each function/capabilities criteria relationship.

The third technique is also based on an evaluation matrix and is often referred to as a design evaluation matrix. In this technique, candidate subsystem functions are listed and compared against selected criteria for allocation (response time, error rate, operability, cost, etc.). As in the case of the screening worksheets, the evaluation criteria are weighted since some factors are obviously more important than others. Each of the function/evaluation criteria relationships is assigned a numerical score, as to how each function best meets the selected evaluation criteria. This third technique is well suited for use in complying with MIL-H-46855 requirements (i.e., Paragraph 3.2.1.4 of that specification). Human engineering criteria such as that in MIL-STD-1472 may be used as the selection evaluation criteria.

Procedure: The procedure for accomplishing the first of the three functional allocation trade techniques is actually the same as the procedures for accomplishing some of the other human factors analysis techniques. In other words, once one of the alternatives for a particular function is tentatively chosen, the alternative should be evaluated for use by

performing one of the analysis techniques on it. For example, the time line analysis technique should be used to evaluate an allocation trade where either operators or equipment are chosen to perform time critical tasks. The resulting allocation choice is then the solution that best meets the system time requirements. In a similar manner, other allocation trades may be accomplished to evaluate man-machine functional performance in terms of reliability. The following paragraphs will indicate which techniques are best suited for testing particular performance parameters.

Functional allocation screening worksheets are constructed by listing each of the several functions to be allocated on the left side of the worksheet. Two sets of evaluation criteria are listed across the top of the sheet. The first set pertains to operator capabilities; the second set pertains to equipment capabilities. Each of the capabilities evaluation criteria is taken from the often used "Fitts List" (Table 3.9-6). In order to balance out each of the evaluation capabilities, each one against all the others, numerical weightings have been assigned as appropriate for the system being analyzed. For example, "response to signals" may be particularly important as compared to "inductive reasoning" and it should therefore be weighted more heavily. Although not a part of the "Fitts List", such factors as cost may be added to these other characteristics. Such parameters are generally considered for evaluation using the design evaluation matrix technique discussed in the following paragraph. Whenever an evaluation characteristic (across the top of the sheet) is applicable to a listed function (left side of sheet) a weighted "X" is placed in the column/row intersection.

The actual evaluation is made by totaling up each of the weighted "X's" for the "operator" versus the "equipment" allocation. The results of the allocation are tabulated in the far right-hand columns as either "operator", "both", or "equipment". The "both" column is used when the sums from both sides of the worksheet come out to be within approximately 80% of each other. In this case, a more detailed analysis may be required to obtain a detailed breakout of operator or equipment allocation. If a more precise evaluation of each of the functions is desired, a numerical score (e.g., 1-5) may be used to indicate how well a particular "Fitts List" evaluation characteristic applies to a function. This procedure is used in the Figure 3.9-5 construction. The number entered in the column/row intersection is the weighted evaluation factor times the score. As with the simpler method indicated above, the total scores are added up on each side of the worksheet to obtain a proposed functional allocation. It should be noted that whereas this technique does not insure the absolutely best allocation of functions, it goes a long way beyond the "gutfeel" method so often used.

Construction of the design evaluation matrix is similar to the functional evaluation screening worksheet in that the functions are listed along the left side and the evaluation factors are listed across the top of the sheet. The main difference is that the trade to be performed is not necessarily between man or machine for a particular single functional listing. The trade to be performed is between each of the functional alternatives listed along the left side of the sheet. Another difference between the two techniques is that the functional lists for the design evaluation matrix tend to be of several equipment alternatives rather than just operator versus equipment alternatives (See Figure 3.9-5).

The evaluation characteristics listed across the top of the sheet pertain more to performance parameters than to inherent capabilities. The evaluation characteristics should be weighted and the suitability of a particular functional alternative to an evaluation characteristic should be scored on a scale of 1 to 5. The addition of each of the weighted scores determines the best alternative.

Use/Validity: Initial function allocations are typically obtained from information taken from mission requirements, functional flows, or other preliminary analysis diagrams. Function aspects such as difficulty, priority and criticality are appraised and operator/equipment methods for meeting the requirements are evaluated. The results of the function allocation trade are used to: a) determine impact of crew tasks, skills and information needs; b) appraise related crew task capability and limitations; c) identify corresponding control/display concepts; d) trade specific and detailed control/display/crew performance capabilities; e) perform extensive task analysis and workload evaluations; and f) identify control/display/crew operations requirements in order to proceed to g) crewstation configuration development.

These techniques are compared to other human factors engineering analysis techniques in Table 3.9-4. Functional allocation studies are best performed early in the program. Although there are variations in the choice of specific techniques, they all may be considered to be of average complexity. They may be used for either gross or detailed analysis of functions but are used more often for gross functional allocation.

Several functions may be simultaneous by the use of one technique worksheet. The time taken to perform the analysis should be short to medium, depending on the scope of the functional allocation effort. The results of the effort will be used equally by managers and analysts. The relative cost and cost effectiveness are both average.

3.9.4.7 Time Lines

Description: Time lines (or timelines) are one of the most basic techniques used by HFE analysts. The two parameters in which HFE analysts are most interested are time and errors. There is no better way to analyze just the parameter of operator time performance than by the use of time lines. Time lines serve two purposes. First, they permit an appraisal of time-critical sequences to verify that all necessary events can be performed. Secondly, they provide an integrated task time chart to assess the occurrence of incompatible tasks and to serve as a baseline for workload evaluation. A typical time line example is shown in Figure 3.9-6.

Procedure: Each time line should be related to a higher level functional requirement. The functional flow title and number should be indicated on the time line sheet for reference (see Figure 3.9-6 sample). Other information such as location of the function and the type of function is desirable. Each of the subfunctions or tasks are numbered and listed along the left side of the sheet. The time units of interest (hours, minutes, or seconds) are indicated and, at the same time, a scale of suitable length selected such that the total time period of interest fits onto the worksheet. It is recommended that once the scale for a sheet is chosen, it be adhered to for all portions of that time line sheet.

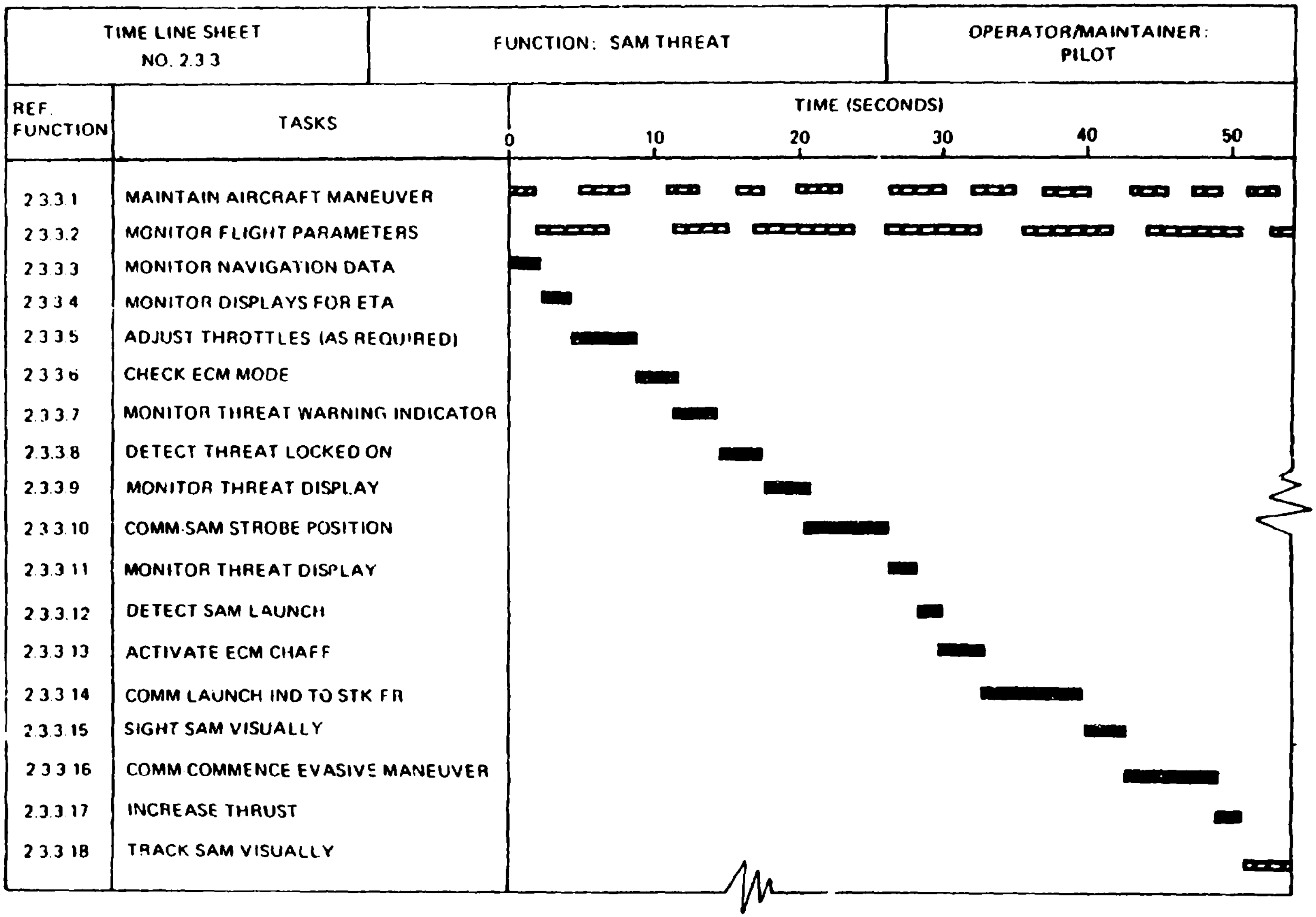


Figure 3.9-6. Sample Time-Line Sheet

Use/Validity: Almost all the techniques previously presented are sources of data to be used in preparing time lines. Generally, the most common source of material for a time line analysis is a detailed level functional flow diagram; one that is sufficiently detailed to have tasks allocated to the operators as the result of functional allocation trades. Table 3.9-1 shows the wide variety of applications or outputs for which time line analysis data may be used.

Table 3.9-4 indicates the relationship between time lines and the numerous technique evaluation characteristics. Review of this table indicates that time lines are best used during concept formulation and after DSARC I but before DSARC II. They are of average complexity to develop, and they are equally useful for analysis of either gross or detailed operator procedures. They are well suited for the analysis of either an individual operator's tasks or several operators' tasks, as long as all tasks are placed on the time line sheet. Compared to other analysis techniques, time lines take slightly less than an average amount of time to perform. They are easy to read and understand, and they are therefore of use to both managers and analysts. Their relative cost is medium and their cost effectiveness is slightly above average. Although not indicated in Table 3.9-5, they are extremely cost effective for use in analyzing simple operator tasks where time is the critical factor.

3.9.4.8 Flow Process Charts

Description: Flow process charts (FPC's) are basically plots of the sequence of operator activities or information transfer as a part of a system. The plots or flow of activities and information exchange are plotted in time sequence. Figure 3.9-7 is an example of such a plot. It is very similar to the information flow chart mentioned previously. The difference between the two techniques is that the FPC's use a wider variety of symbology and are generally performed at a more detailed operator task level. The FPC symbology is shown in Figure 3.9-8. The symbology is adopted from the ASME (American Society of Mechanical Engineers), flow chart standards.

Procedure: The FPC is oriented vertically, frequently with a time scale to one side or another of the function or task symbology. Each task performed by the operator is recorded with the proper symbology (see Figure 3.9-7) and with a brief description of the task. A time value, and perhaps a distance, are also recorded if appropriate. Start and stop points of the charted activity are indicated.

In preparing these charts, the HFE analyst should ensure that all logical possibilities are included, all loops are completed or terminated in a valid exit, and all tasks are capable of being performed by the operator. The following aspects must be considered: a) how each operator will make decisions, b) what the criteria are to be used for decision making and c) what information requirements must be met to provide a basis for decision making.

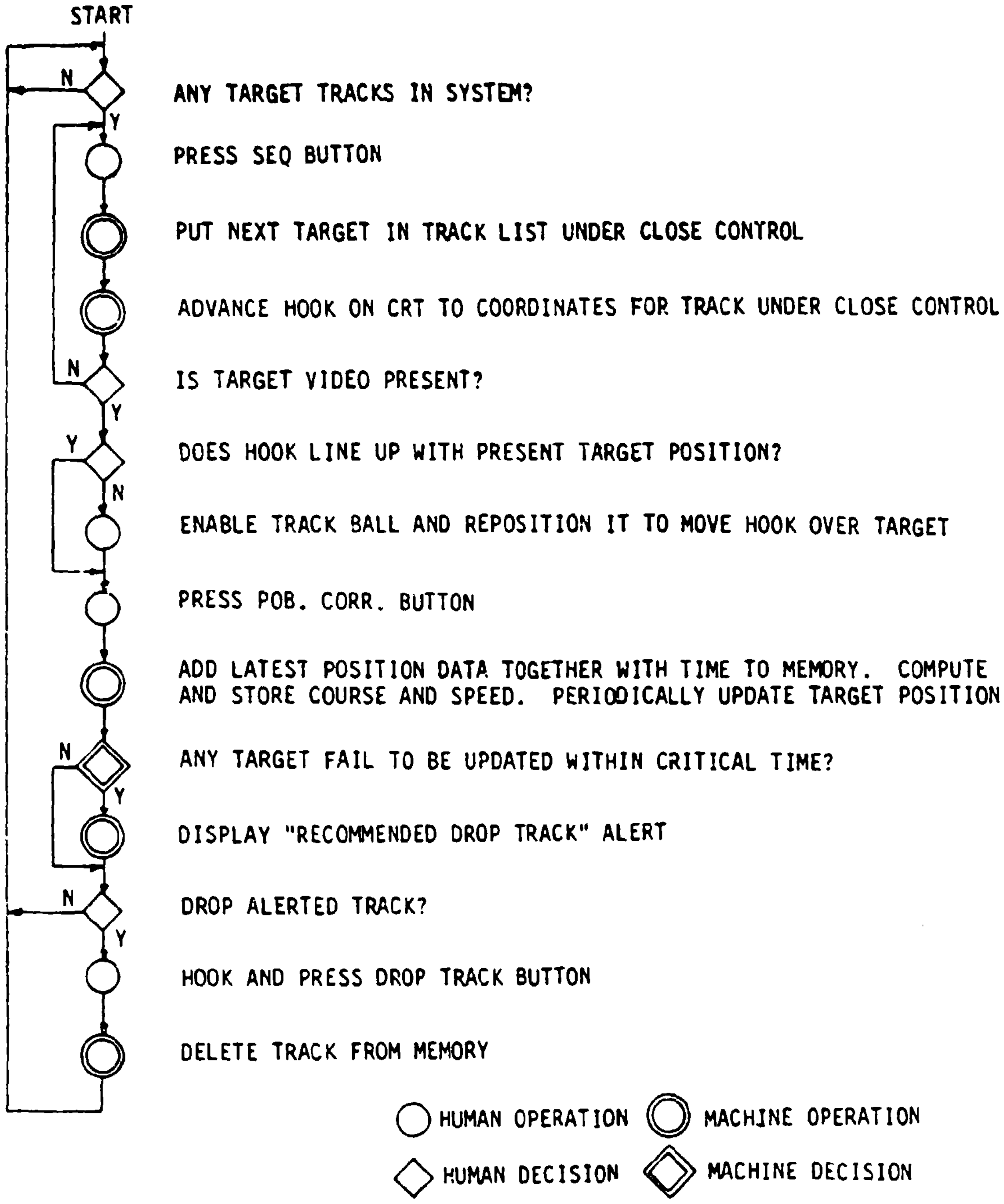
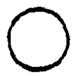
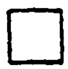


Figure 3.9-7: Sample Flow Process Chart

Symbology

 Operate - an action function, to accomplish or continue a process. (Sometimes used for received information)

 Inspect - to monitor or verify quantity or quality. An inspection occurs when an object is examined. (Sometimes used for action)

 Transmit* - to pass information without changing its form.

 Receipt* - to receive information in the transmitted form. (Sometimes used for stored information)

 Decision - to evaluate and select a course of action or inaction based on receipt of information.

 Storage - to retain. (Sometimes used for transmitted information)

* - Mode of transmission and receipt is indicated by a code letter within the

 and  symbols.

V - Visual
E - Electrical/Electronic
S - Sound (verbal)
IC - Internal Communication
EX - External Communication
T - Touch
M - Mechanically
W - Walking
H - Hand Deliver

(Special combinations of symbols are shown in Figure 3.9-10)

Figure 3.9-8: FPC and OSD Symbology

Use/Validity: The purpose of constructing the flow process charts is to aid in developing and evaluating concepts for each operator station. If a single operator station is being analyzed, it is a good technique to use; however, if more than one station is being analyzed, a separate chart must be developed for each station. The operational sequence diagram (OSD), which is discussed in the following paragraph, is a better technique to use for multiple operator station analysis.

Table 3.9-1 indicates the applications or outputs from the FPC's. A comparison of the FPC technique with all of the other manual techniques is indicated in the Table 3.9-4. In summary, the FPC should be used during the earlier program phases. It is of average complexity and may be used for analysis of detailed tasks. The relative time to perform the FPC's is average as compared to other manual analysis techniques. FPC's are used by analysts more than managers. Their relative cost to perform is average, as is their relative cost effectiveness.

3.9.4.9 Operational Sequence Diagrams

Description: The operational sequence diagram (OSD) is probably the most powerful single manual analysis technique that the HFE analyst can use. This is because of all the outputs and applications that derive from its use (Ref. Table 3.9-1). It is particularly useful for the analysis of highly complex systems requiring many time critical information-decision-action functions between several operators and equipment items.

The OSD has been used on numerous Navy programs such as Polaris, ASMS, VPX, and the Air Force E-3A (AWACS). It was derived from the flow process charts (FPC). It retains the same basic attributes of the FPC. It is a graphic presentation of operator tasks as they relate sequentially to both equipment and other operators. OSD symbology is also adapted from the ASME flow chart standards. The OSD is an FPC expanded in terms of channels or work stations.

By using symbology to indicate actions, inspections, data transmitted or received, data storage, or decisions, the OSD shows the flow of information through a system. The information flow is shown in relation to both time and space (work stations). The OSD may be used to develop and present the system reaction to specified inputs. It is one of the cheapest and quickest ways to simulate the system. Whereas mockups and prototypes may be more complete for some simulation aspects, they are more expensive. Computer programs are also generally more expensive depending upon how often they are used. In the OSD, the interrelationships of operators and equipment (man-machine interfaces) are easily visualized. Whenever information transferred is mismatched with the format to be received, interface problems are clearly indicated. Operator activities are sequentially categorized. Decision and action functions are clearly identified and task frequency and load become obvious.

Procedure: A sample OSD is shown in Figure 3.9-9. An explanation of OSD symbology is included in Figures 3.9-8 and 3.9-10. In a similar manner to the FPC's, the flow of events and tasks is always from the top of the sheet toward the bottom. The operators and machines are entered into the column headings

on the OSD. It generally proves convenient to place in adjacent columns the operators and the machines with which they interface. Also, it helps to group together all of the operators and equipment of a specific functional division (e.g., Weapons Control). In some cases, the operators or maintainers and equipment in a system will have been specified by the time the OSD is constructed. However, if the men and machines have not been specified, the analysts will have to specify them tentatively. In either case, in the process of doing the OSD, it may be found that too many or too few operators and/or machines have been selected. The reason for doing the analysis is to "drive out" crew size and interface requirements.

The OSD is initiated by the first event designated by the scenario (Reference previous paragraph). The event and event times are written in the two left-hand columns. All of the machines or men who will receive the input are shown and the transmission/reception mode is noted by using the appropriate letter code. The subsequent actions taken by the crew/equipment (operations, transmissions, etc.) as they react to the input are shown. External outputs are plotted in the far right-hand column. As the reactions are plotted, the analyst should be cognizant of the time required to perform the actions. The process of plotting the inputs and subsequent reactions is continued as dictated by the events given in the scenario or narrative. No attempt is made to keep the actual space between scenario time events proportional to the time itself.

It is important to remember that the reader of an OSD should be clearly shown the operation of the system, and all of the steps shown on the OSD should be described by a brief notation describing the process or action. As with

SECOND-LEVEL FUNCTION: 2.4.1 PERFORM PRESTAGING CHECKOUT

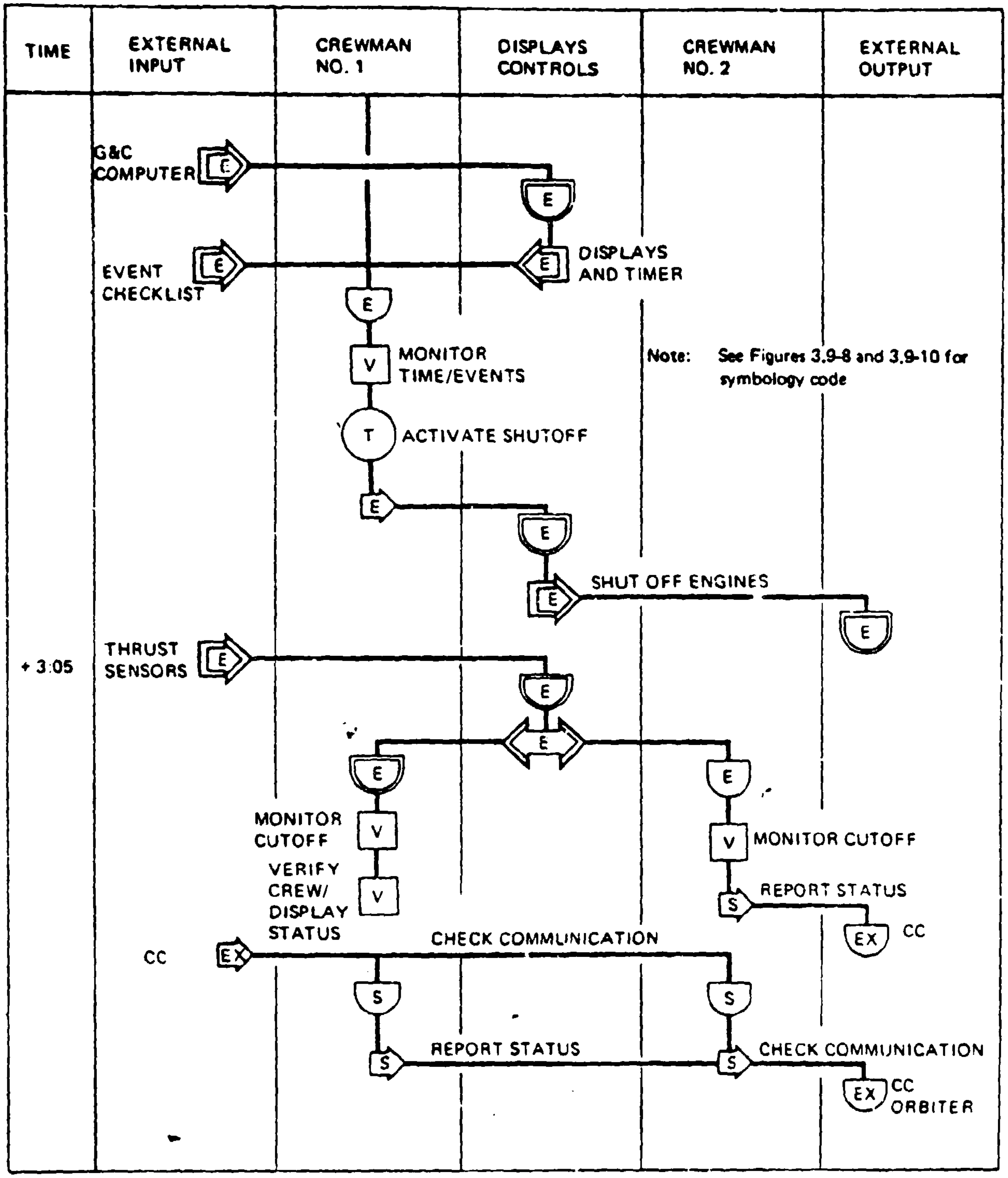


Figure 3.9-9. Sample Operational Sequence Diagram

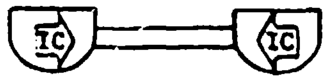
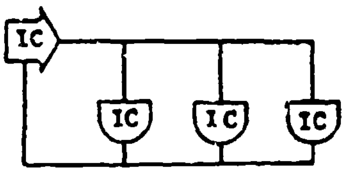
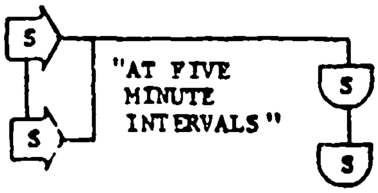
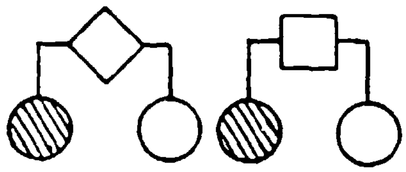
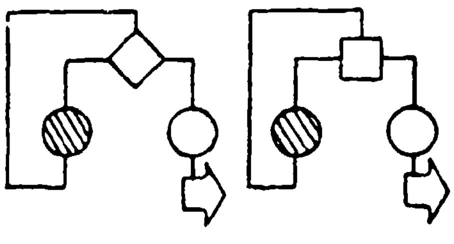
	Exchange of information or discuss- ion by two principals involved. Used with appropriate source codes.
	Acknowledgement of receipt of information used with appropriate source codes.
	Continuous flow of information throughout event Receipts are picked off where needed in sequen without repeating entire process. Time inter- vals may be indicated as shown.
	Double symbols indicate automatic transmission, receipt, storage or operation.
	DECISION: LEFT NO; RIGHT YES INSPECTION: NO GO; GO
	A repeated process usually repeated until a desired condition exists before continuing. Note: The last repeat of several may be shown in normal sequential order to give a clearer picture of the event.

Figure 3.9-10: Special Combinations of OSD Symbols

the case of the FPC, the HFE analyst should be sure that all logical possibilities are included, all loops are completed or terminated in a valid exit, and all tasks are capable of being performed by the operators.

Use/Validity: The reason the OSD is so useful in terms of outputs is simply that so much must go into it. The integration of all the data that go into a typical OSD is generally a tedious and time consuming process. Experience has shown that the construction of OSD's requires trained individuals with analytic skills.

The information to construct an OSD may come from scenarios, functional flow diagrams, time lines, decision/action diagrams, work station layouts, or other sources. If the HFE analyst is dependent on other organizations for this information, he must conduct numerous interviews of other organization personnel or have an extremely efficient program requirements documentation effort to draw on.

Table 3.9-1 indicates several specific output applications that result from performing an OSD analysis. Table 3.9-4 indicates the numerous evaluation characteristics of the OSD as compared to other analysis techniques and indicates the OSD should be used during the earlier program phases. It is a complex technique and may be used for analysis of detailed tasks. It is particularly useful for the analysis of several tasks that are occurring almost simultaneously between several operators or between several operators and equipment. Because of the complexity of the OSD, it tends to take a relatively long time to perform. Its cost to perform is relatively high (two man-years for the ASMS concept formulation phases), but its payoff in terms of a paper system test and verification gives it an "average"

relative cost effective rating. Also, it should be emphasized that the OSD is like any other paper simulation technique in that it must be validated as soon as practical in an environment closely similar to the actual working environment. Although much more complex, OSD's are somewhat similar to decision/action diagrams. Often when decision/action diagrams are used, OSD's are not.

Another technique that is similar to the OSD is the functional sequence diagram (FSD). Its format is very nearly identical to the OSD's. It is easier to construct but does not provide as much useful information as the OSD. The difference between the two techniques is that the FSD does not make a distinction between operators and equipment.

3.9.4.10 Task Descriptions

Description: Task descriptions, as a distinct analysis technique, are not used as much today as they were several years ago. Newer manual and computer-aided techniques are being used in place of them. However, they are presented here because they still have unique characteristics that are suited to particular analysis applications. Task descriptions are one additional human factors engineering tool that can be used to help define personnel requirements in complex systems. Taking the data developed by the use of previous analysis techniques, task descriptions can be developed which will:

a) Test the man/machine system interface to ensure compatibilities with operator abilities;
b) Contribute to the development of training programs, training manuals, and job aids for personnel who will be involved in the operation and maintenance of the system; and
c) Assist in the personnel procurement and associated manpower planning process.

Task descriptions are developed from the functional allocation process data. Task descriptions provide a basic reference for subsequent design and development of the entire personnel subsystem. A task description is essentially a statement of basic task requirements. It can assist in design finalization by identifying operability or maintainability problem areas, or by defining operator activities with specific equipment. Task descriptions received considerable emphasis in the Air Force Systems Command Manual 375-5 (Ref. 33) system engineering process several years ago. In a few instances, the same worksheet forms are still being used today.

The level of detail in an adequate task description depends largely upon the complexity and criticality of a given system, and/or the expected levels of difficulty in training and manning the system. Generally, the level of detail for specifying task activities is about the same as that used in an instruction manual for a novice. A good task description could easily become a procedural manual for the job. Figure 3.9-11 is an example of a detailed task description, and it illustrates the kinds of elements that must be identified.

Procedure: Task descriptions should proceed from general task statements to specific display, control, decision activity details. In the example of Figure 3.9-11, functions that have been allocated to man during the functional allocation process are listed along the left side of the analysis form. Under the heading "Elements" the task activities are listed. These are tasks that may be classified as actions, perceptual motor activities, straight monitoring, communicating and decision making or problem solving.

POSITION: PILOT
DUTY: VEHICLE CHECKOUT AND START

TASK	TIME (MIN)	ELEMENTS			REMARKS (PRECAUTIONS, ETC.)
		CONTROL	ACTIVITY	INDICATION	
1.1.1 ENGINE START	0.1		OBSERVE	GROUND CREW SIGNAL	PROCEDURE PERFORMED PER CHECKLIST
	0.05	APU BATTERY SW	PRESS/MONITOR	ON	DECISION TO USE APU
	0.05	APU FUEL SW	PRESS/MONITOR	ON	
	0.05	APU START	PRESS		
	0.5		MONITOR	START	
	0.05	ENGINE FUEL MASTER SW	PRESS	ON	
	0.05	AUX FUEL PUMPS	PRESS	ON	
	0.05		OBSERVE	FUEL PRESSURE	VARIABLE TIME ESTIMATE
	0.05	ENGINE START	PRESS		
	0.05			ENGINE PARAMETERS	

Figure 3.9-11: Sample Task Description

The associated controls and/or displays are listed along with the activity. Remarks that have to do with the activity are included in the far right-hand column. These remarks, which might include contingencies which can severely affect the mission or system success, are identified; particularly because of their impact on operator skill level requirements. Major environmental conditions affecting a mission cycle, or any segment of it should be included in the remarks column. Machine malfunctions that might occur during a critical mission task should also be included. If there is a particularly high probability of human error, this data should be indicated in the remarks column. The corresponding times for each of the operator task elements have been estimated and included in a column next to the task column. It should be noted that task descriptions need not be highly structured, but can be modified to fit the requirements of various systems.

Use/Validity: Table 3.9-4 summarizes the characteristics of task descriptions as compared to all the other analysis techniques. Task descriptions are prepared at any time during the program; however, they are of less value during the time period following DSARC III. They are relatively simple to construct and are used for either gross or detailed analysis. Task descriptions are used to describe several simultaneous tasks but are better used to show the single thread sequential relationship of one task occurrence at a time. The time required to prepare a task description is average as compared to any other analysis technique. The table indicates that both managers and analysts have equal use of the technique. The relative cost to prepare a complete task description is average. The relative cost effectiveness is average. The technique,

being more narrative in form than pictorial, gives less visibility to items of analysis interest such as task or time relationships. Problems which are generally discovered as a result of performing time line analysis are not as apparent as a result of using this technique. The length of the time blocks used in time line sheets "displays" the time relation between each block. This relationship is harder to see as just a number in task descriptions.

3.9.4.11 Workload Analysis

Description: Workload analysis provides an appraisal of the extent of crew task loading, based on the sequential accumulation of task times. Application of this technique permits an evaluation of the capability of the crew to perform all assigned tasks in the time allotted by mission constraints. As capability is confirmed, hardware design requirements can be more precisely designated. Conversely, as limitations are exposed, alternate function allocations or crew task assignments are considered and implemented.

Workload analysis or workload profiles, as they are often referred to, are a graphic presentation of an operator's workload constructed by plotting percentage of task involvement against a time base (see Figure 3.9-12). Although workload analysis depicts individual activity, its greatest effectiveness is realized when several operator/maintainer positions are plotted together on the same graph. By doing this, any unbalanced workload distributions among the operators become readily apparent. Earliest possible workload appraisals are needed to assure that resulting task loads are within the scope of the crew

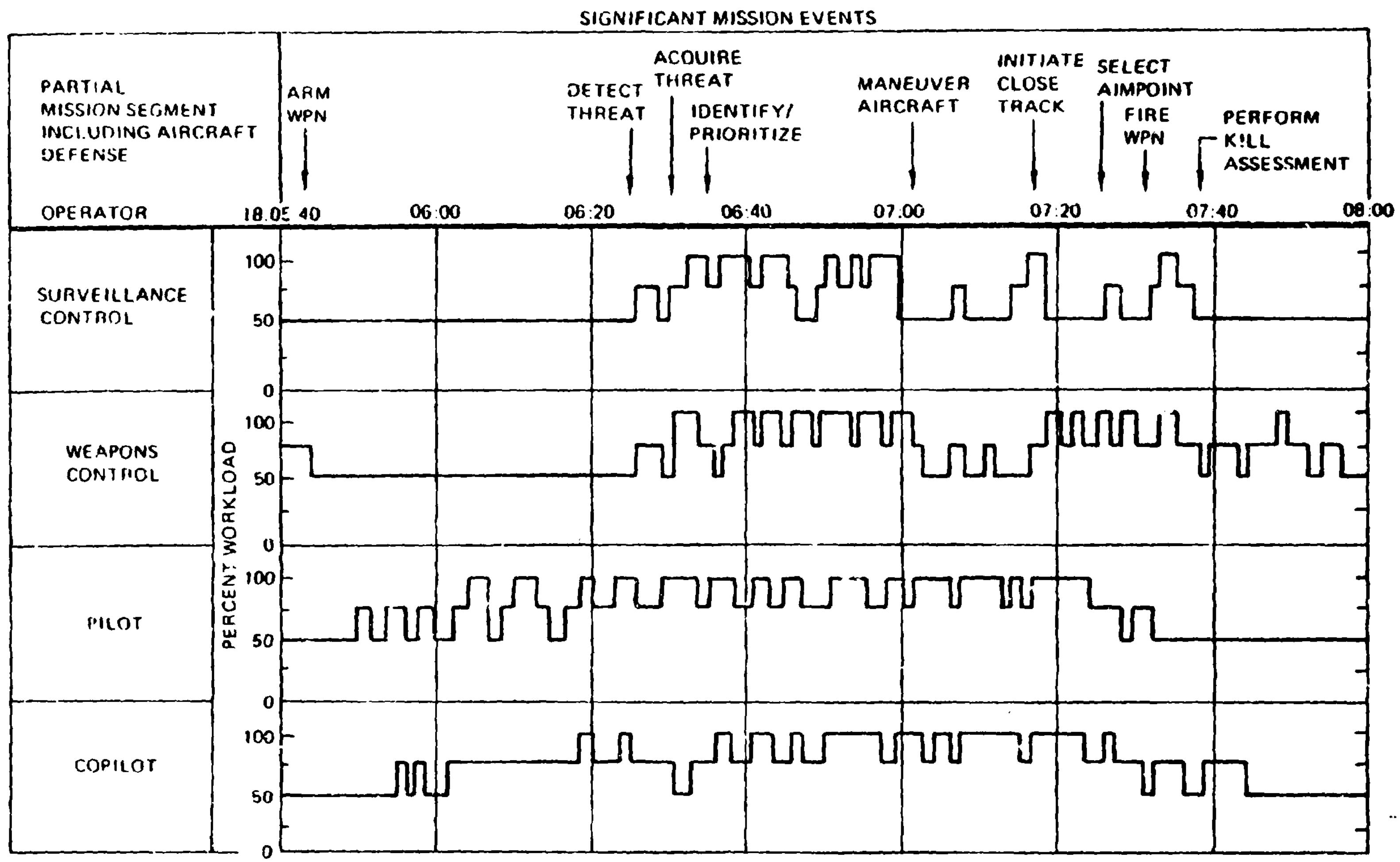


Figure 3.9.12. Sample Workload Analysis Profile

size and capability. Workload analysis was developed to verify that no combination of tasks required more task load capacity, or time to perform than is available. One of the more recent concepts in workload analysis has been to divide the operator tasks into categories corresponding to his perceptual-motor channels. This analysis refinement does not necessarily have to be accomplished in order to successfully perform workload analysis. However, the more detailed the analysis the better the output data. In some situations, operators can effectively perform more than one task at one time. However, it is obvious that an operator cannot accomplish two tasks simultaneously if both tasks require the use of a single perceptual-motor channel nearly 100% of the time. The workload analysis chart exposes such conditions when properly developed.

When such conditions are noticed, it is apparent that one of two things must be done. Either a task must be given to another operator or the operator must be provided with some type of equipment assistance.

The task loading estimates may come from several sources. For example, the task may be the same as, or similar to, another task in another system which is in actual operation. Task time data from previous systems is generally the most reliable since it has been verified in practice. When such information is not available, the next best data is from operators who have performed similar tasks. It is desirable to get estimates from several operators since their evaluations will vary. The HFE analyst must provide the operator with enough detail to enable him to make an estimate.

When experienced operators or other data sources are not available, the HFE analyst, together with knowledgeable project designers, must make an "educated guess" about the task workload implications. The HFE analyst will have to do what he does with all problems of this sort; he will have to break the task down into its simplest elements and extrapolate from what he knows about other subtask elements.

Procedure: In application, workloads are estimated at either a gross level or detailed level in terms of both time and number of perceptual-motor channels considered for analysis. As workload situations tend to become more critical, shorter time increments are examined. Also, as workload increases for a given situation and as the situation becomes more critical, it is desirable to make workload assessments on the basis of each of the operator's perceptual-motor channels. These are generally listed as: external vision (distance vision), internal vision (within the cockpit or console panel area), left hand, right hand, feet, cognition, audition, and verbal channels.

Workload calculations are based on estimates of the time required to perform a given task divided by the time allowed or available to perform the task. The analyst is cautioned that if he evaluates workload by considering each of the distinct perceptual-motor channels he cannot equate a 75% loading on each channel to an overall 75% loading. The precise summation effects of all or several of the channels cannot be accurately predicted. Quite possibly the results of a 75% loading on each channel would result in a total overload situation ($>100\%$). The analyst is also cautioned not to average workload over the time increments being considered. A workload estimate of 100%

and an estimate of 50% for two sequential tasks occurring within a given time increment must be considered as an overall estimate of 100% (not 75%). If it is necessary to provide visibility to the 50% loading situation, then the time increments must be broken down into smaller time periods. The point of the analysis is to discover significant workload conditions including peaks, not to mask them out.

In general, workloads over 100% are inacceptable, between 75% and 100% are undesirable, and under 75% are acceptable provided that the operator is given sufficient work to remain reasonably busy. Prior to its current revisions, MIL-H-46855 contained an appendix that described the conditions where operator workload analysis should be performed. The implication was that operator loading in excess of 75% should receive special scrutiny.

Since the process of estimating workload is based on the estimate of time required to do the task, it is only as accurate as that data. It is also limited by the knowledge of the time available to do the task, and it is limited by the unknown discrete channel summation effects. Depending on these variables alone, the accuracy of most workload assessments are probable in the ±20% range. If more accurate assessments are required, full scale simulations of the crew tasks may be necessary.

The workload analysis may be made up of a simple continuous chart from the beginning to end of a mission, or there may be several charts, eacn of which expands a particularly critical segment of the mission. As previously indicated, the time scale should be commensurate with task complexity, i.e., 15 minute intervals may be all that is necessary for simple workload analysis evaluations and 5 second intervals may be required for more complex tasks. Whatever intervals are used should be common for the total group of tasks and operators when they interact.

Use/Validity: Table 3.9-1 indicates the applications or outputs of workload analysis. An evaluation of workload analysis as compared to other techniques is shown in Table 3.9-4. Workload analysis is most generally performed after DSARC I when sufficient other analysis has been performed in order to develop the input data to workload analysis. It may continue past DSARC II and possibly past DSARC III. The complexity of this analysis is average as compared with other techniques. It may be used to perform a gross or top level (several minutes at a time) analysis of operator workload or a very detailed (a few seconds at a time) analysis. If several workload profiles are combined on one page, it may be used to compare several simultaneous tasks. The time to perform this manual workload assessment is about average as compared to other analysis techniques. Because of the definition of work overload and the notion of the use of separate perceptual-motor channels, this technique is best used by analysts alone. If used by managers, a detailed explanation must accompany the data. The relative cost to perform the analysis is average, as is the relative cost effectiveness as compared with other analysis techniques.

3.9.4.12 Correlation Matrix

Description: The correlation matrix, or chart, is one of the simplest and easiest analysis techniques to use. It is constructed in a manner similar to a highway map mileage chart. It is generally used after the development of OSD's for the purpose of summing up all of the links between each of the operators, operator workstations, and/or equipment. Figure 3.9-13 is an example of a correlation matrix. It is a summary of the communications occurring during a hypothetical function. Although correlation matrices are of use by themselves to determine the frequency of use of the various links or interfaces between system man/machine components, they are more often used as an intermediate analysis step between the OSD and link analysis. The following section indicates how the correlation matrix data are used as an input to link analysis. The reason for having a list of the relative frequencies of use of the communcation paths, or whatever sort of man/machine links there are, is to locate each of the man/machine workstations (or function) so that the paths between them are as short as practicable. For example, if crewman "A" is required to pass ten times as many messages to crewman "B" as he does to crewman "C", then it stands to reason that he should be located much closer to crewman "B".

Procedure: All of the man/machine components of the system that are listed across the top of the OSD and that are of interest to the analyst are listed in a vertical column. As can be seen from the example in Figure 3.9-13, parallel lines are extended to the right at angles up and down from each of the listed workstations. This results in diamond shaped blocks at the intersections of the rows coming out from each listed workstation. The number of links between each

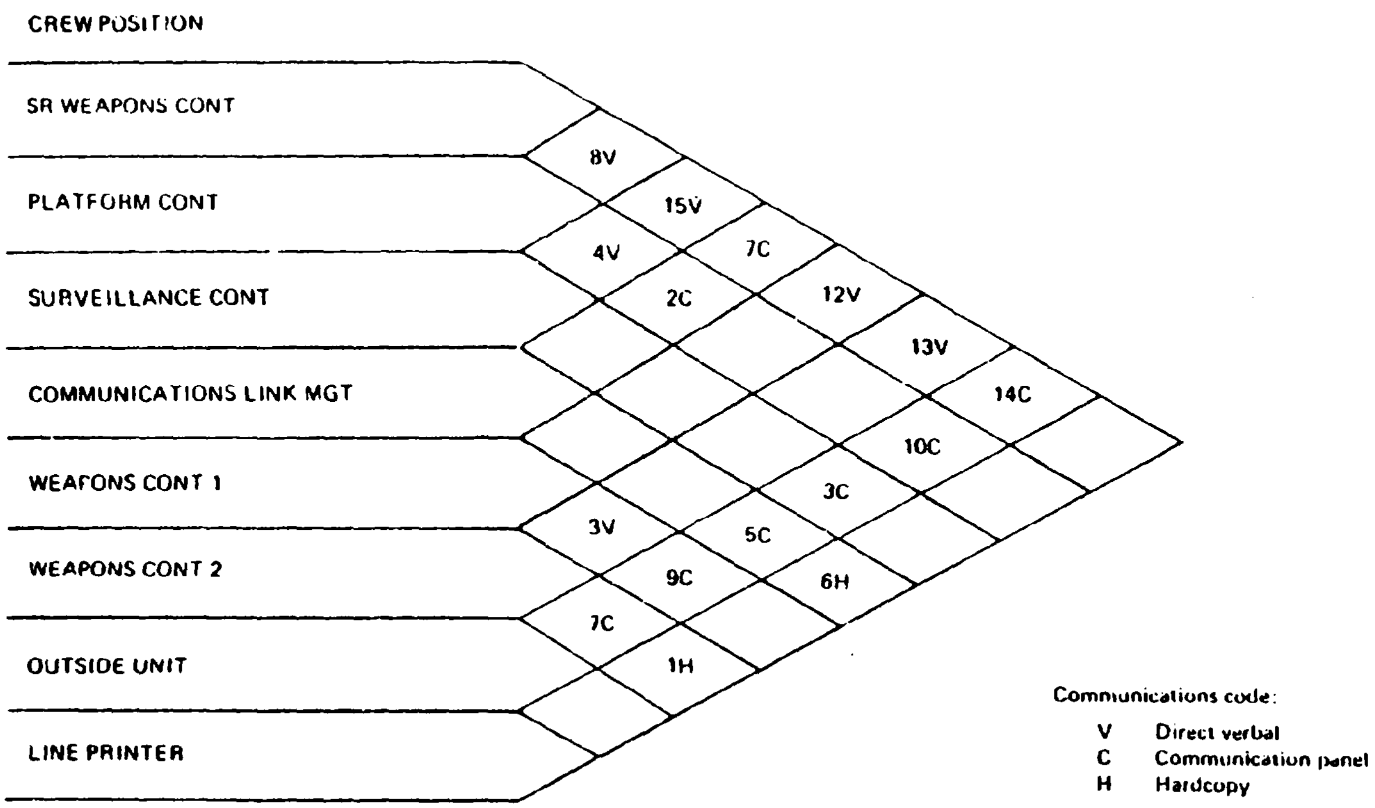


Figure 3.9-13. Sample Correlation Matrix (Chart)

of the listed man/machine workstations are counted up from the OSD (each link should be drawn in on the OSD). The total quantity of links is placed in the diamond shaped block that represents the intersection of the rows coming out from the workstations.

Although not absolutely required, it may be just as important to add a letter symbol as an indication of the estimated criticality of the data transfer, or links, between workstations. The intersecting blocks and total matrix would, of course, have to be made large enough to put all of the data as to number of links of each kind (high, medium, low criticality) in each of the intersecting blocks. Letter symbology may also be used to indicate the type of data link, e.g., direct voice, interphone, TTY.

Use/Validity: Table 3.9-1 shows the various applications of the correlation matrix data. Table 3.9-4 evaluates the technique against all the other analysis techniques. As previously indicated, the timing for the performance of the correlation matrix is dependent on the OSD. It should be performed during the Concept Formulation phase or after DSARC I or whenever the OSD analysis has taken place. The correlation matrix is a very simple technique to use. It is best used to summarize man/machine links at a detailed level of analysis. Of course, it is used to summarize these links or data paths for several tasks for several workstations occurring over a period of time that was analyzed by the OSD. Because of its simplicity the correlation matrix takes only a very short time to perform. Correlation matrices are useful to both managers and analysts. The relative cost to perform is low and the cost effectiveness is high when compared to other analysis techniques.

3.9.4.13 Link Analysis

Description: This analytic tool is often used as a first step in developing an optimized panel, workstation, or work area layout. It is frequently used to verify the adequancy of design layout. Its purpose is to depict graphically the frequency and/or criticality associated with each of the various interactions occurring between operator and equipment and/or between one operator and another. The HE analyst first starts with the operator and equipment interaction (links) that were established during functional analysis. The data generated by the OSD's and the correlation matrix are the major source of link analysis data. If the link analysis is being performed on a particular panel layout, there may be little of the operator-to-operator links involved. If the link analysis is performed on a system such as the E-3A (AWACS) tactical compartment, however, the operator-to-operator interactions are extensive.

There are basically two types of link analysis as represented by the two previously indicated situations: the panel layout and the tactical compartment (or other type of multiple operators work area). The term link analysis is equally applicable to both situations. The terms adjacency layout diagrams and flow diagrams are sometimes used to describe link analysis as it pertains to multiple operator work areas. Figure 3.9-14 shows an adjacency layout diagram. The term spatial OSD (SOSD) is sometimes used to describe link analysis of a console or panel layout. As its name indicates, the SOSD is the OSD flow of data and functional symbology superimposed on a picture of the particular console or panel or interest. Figure 3.9-15 illustrates this. The items that are missing from the OSD

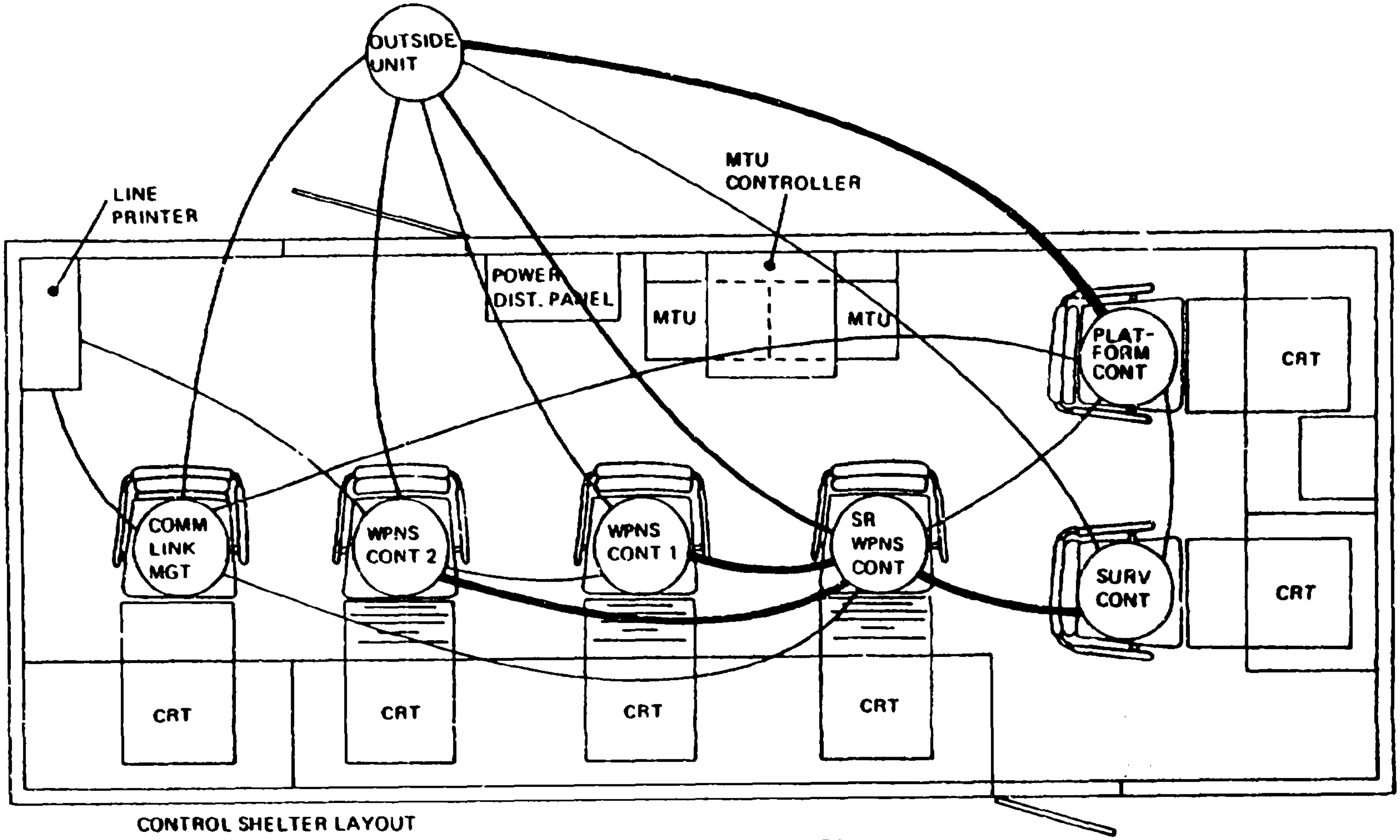


Figure 3.9-14. Sample Adjacency Layout Diagram

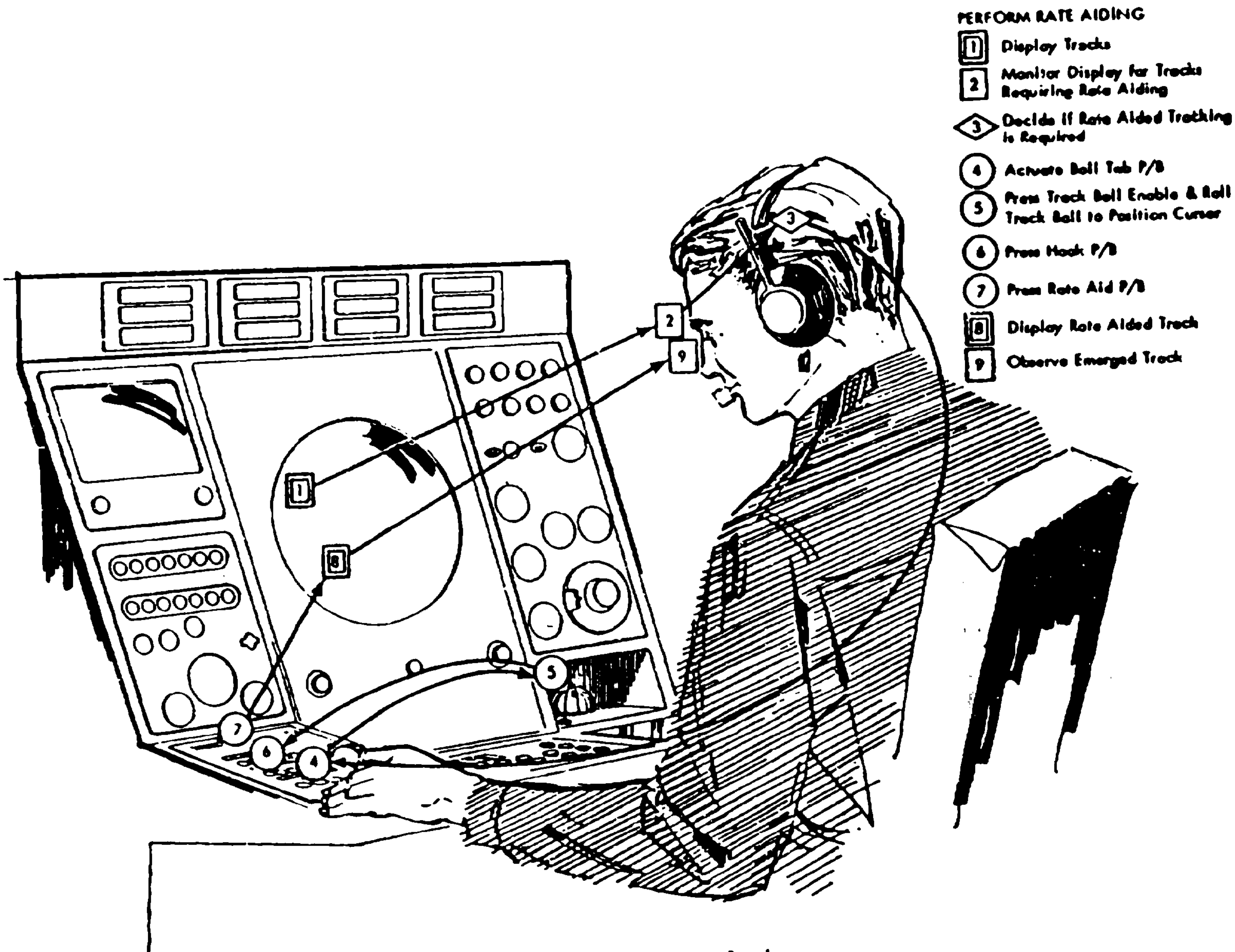


Figure 3.9-15 Sample Link Analysis
(Spatial OSD)

in this form are the time scales, the outside events, and the columns and headings. All of the symbols and links are exactly as they are indicated in Section 3.9.4.9. Operational Sequence Diagrams. Whereas the OSD indicates workstation relationships, it does not do this nearly as well as link analysis does. The spatial OSD may also be used for verifying work area layouts and the adjacency layout diagrams used to verify console layouts. However, the latter situation is unusual.

The adjacency layout diagram type of link analysis is dependent on the correlation matrix. Beginning with the correlation matrix and a console or area layout, all interactions (links) required to perform a particular functional task are examined in terms of the frequency with which they occur and their criticality. If the criticality is assigned a numerical value, it may be multiplied by the frequency in order to obtain a weighted link value. The panel or work area is overlaid with the weighted links permitting a picture of all the interactions taking place within the system being analyzed. The system design is then modified to shorten the distance between the controls or displays or workstations that are connected by the weighted links.

Procedure: There are several variations in the detailed step by step procedure for constructing a link analysis diagram. The variations are dependent on the type of link analysis being used and the type of layout being analyzed, i.e., console or work area. Basically, the first step in performing the flow diagram or SOSD analysis is to choose symbology for

each of the system functions being manipulated or arranged. It is strongly recommended that the OSD symbology be used (see Figure 3.9-8). Symbology for the system components is not as important as the functions because the drawing of the panel or work area shows what the components are without the need for any symbols.

In the case of the adjacency layout diagram special symbols, such as circles for operators and squares for equipment, may be chosen for each of the operator/equipment categories. In this type of analysis the frequency of use and criticality of links between workstations are emphasized rather than the flow sequence. The choice of line coding for each of the various types of links must be made. There is no standard for use as a guide, but the factors that should be considered are frequency of use, criticality, and type of communication link (e.g., Voice, TTY). Often the line width of the link indicates either the frequency of use or the weighted value of the link. The frequency of use times the criticality is the weighted value of the link. A criticality value of 1, 2, or 3 is recommended. The higher the total number (criticality times frequency), the more significant the link. Often this number is labeled right on the link. As previously indicated, the value for the frequency of use comes from the correlation matrix (Figure 3.9-13) or directly from the OSD's (Figure 3.9-9).

In either case, the last step in the technique is to draw on an overlay, or to draw directly onto the design layout, the links and symbols selected. It is important to have selected a drawing that is to scale. If the SOSD technique is being used, the analyst starts at the beginning of the SOSD with the OSD symbology and proceeds to the completion

of the total major task (see Figure 3.9-15). If the adjacency layout diagram technique is being used, the HFE analyst starts with the operator who appears to be the busiest. He places the related components around the operator, moving them, as necessary, to minimize link crossings (if significant) and to shorten link lengths, especially those with high weighted link values. It should be emphasized that additional changes undoubtedly will be required once the system is constructed in the form of full scale mockups or as prototype hardware. Regardless of a paper analysis, the system requires an interactive review.

Use/Validity: Table 3.9-1 lists the applications or outputs for which link analysis data may be used. Table 3.9-4 indicates the comparison between link analysis and the numerous other techniques. In summary, the table indicates that link analysis should be used during the first or middle phases of a program. It is of average complexity to perform as compared to other analysis techniques. It should be used for detailed analysis and like the correlation matrix much of its purpose is to analyze several nearly simultaneous tasks. The time taken to develop a link analysis is average. It may be used for presentation of data to managers but is best used by analysts. Its cost is average and cost effectiveness if slightly better than average when compared to other analysis techniques.

3.9.4.14 Computer-Aided Function Allocation and Evaluation System (CAFES)

The magnitude of human engineering tasks is frequently too great for manual completion in compliance with design/development scheduling requirements, forcing either minimal consideration or heavy reliance on professional experience and judgment. There is need for an integrated, interactive system for more effective human factors engineering efforts, to expedite time consuming HFE task elements in data retrieval and processing. In this regard,

properly designed computer programs can extend the capabilities of the human factors engineer. This section describes such a system for improving and expediting the HFE analysis process. It summarizes the concepts of computer-aided techniques for human engineering support to Navy systems development under a program called CAFES (Computer-Aided Function Allocation and Evaluation System). CAFES is a design support system based on human engineering methods, computer aids, human performance data, and a data management system.

CAFES offers a number of computer aids to HFE that can be applied throughout system development. When fully completed, validated, and implemented, it will provide for a systematic integration of computer and engineering capabilities. As system development progresses, CAFES can be used in initial development and exercised repeatedly throughout development to assist in updating requirements analysis; system trade-offs; definition of design criteria; crew systems design; procedures development; test and evaluation planning; training and maintenance system development; and operational evaluation.

The CAFES submodels include:

a) Data Management System (DMS)
b) Function Allocation Model (FAM)
c) Workload Assessment Model (WAM)
d) Computer-Aided Crew Station Design Model (CAD)
e) Crew Station Geometry Evaluation Model (CGE)

The separate CAFES models are interrelated and can be interdependent, as the inputs to some models can be the outputs from others. For example, a workload analysis (WAM) can evaluate candidate function allocations (FAM) and integrate necessary task sequence/timeline data as a prerequisite to preliminary design development (CAD). This

integration of the various models into one coherent system provides an efficient exchange of data between submodel elements as well as use of common data. Iterative analyses responsive to system or concept changes are also facilitated by the integration.

CAFES can be applied at a gross level during early system concept formulation when system detail is usually sketchy, or, with numerous assumptions, at a detailed level. As system development progresses, the ratio of system detail to system assumptions improves considerably and CAFES analyses can be carried out to much greater detail. This will permit updating of analyses to reflect changes from later submodels and current HFE status throughout the development cycle.

The following paragraphs summarize the concept for each CAFES submodel. The CAFES executive and management system, DMS, and the FAM and WAM submodels are discussed in this analysis paragraph. CAD and CGE are presented in the paragraph on design techniques. More complete descriptions are contained in References 34 through 40. The application of each separate CAFES model in HFE is discussed under each model subsection, however, one use of CAFES is in the integration of the models to produce data and analysis required during new systems development. CAFES model relationships are illustrated in Figure 3.9-16. The interactive applications of these models can produce all the various CAFES results.

For example, the workload analysis by WAM may suggest a re-exercise of the functions allocations in FAM to evaluate different allocation versions; or CGE results may suggest a change in basic configuration layout, to be run on the CAD. Consequently, the fully integrated capability of the CAFES method will be realized when all submodels are completed and interrelated.

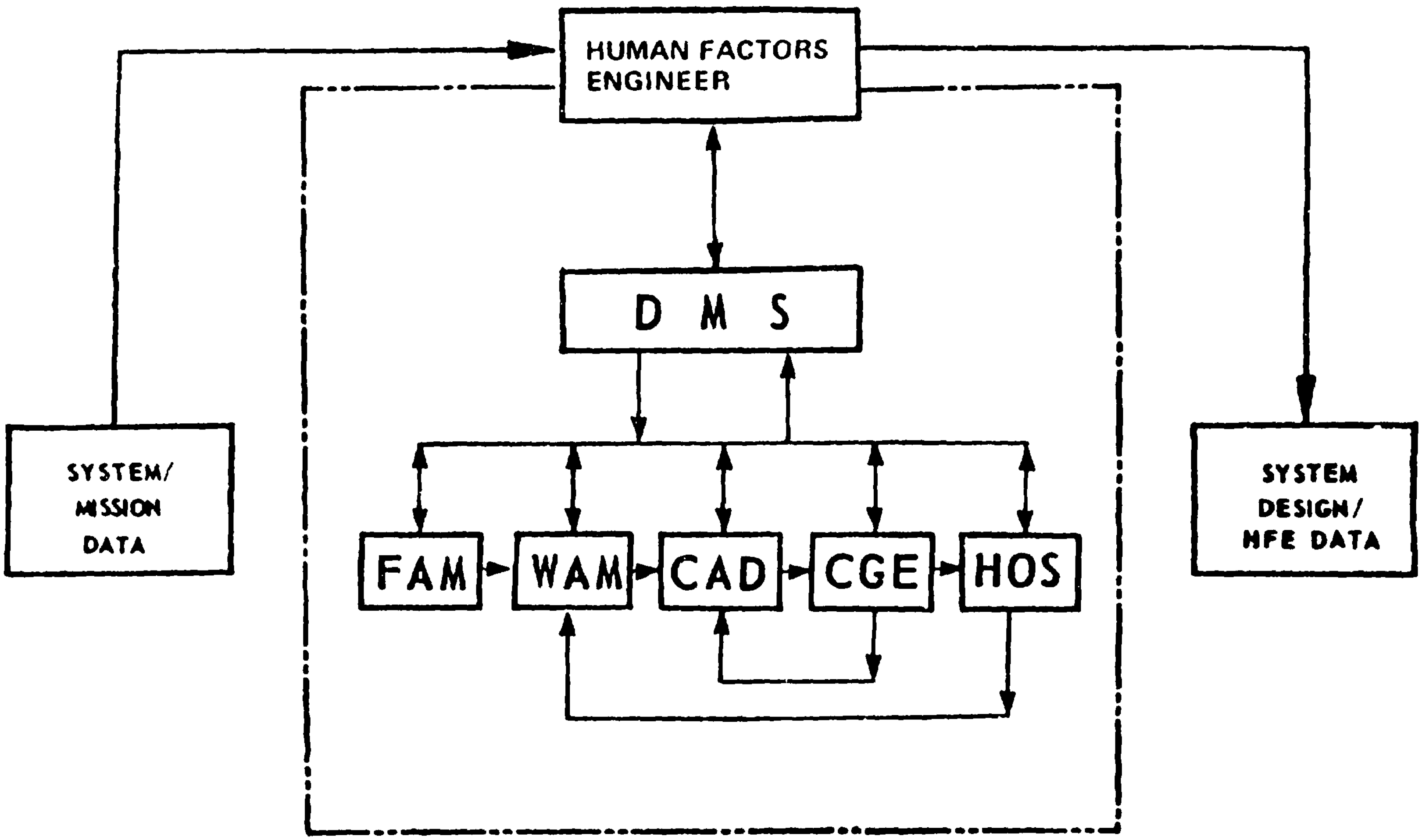


Figure 3.9-16:CAFES Model Relationships

CAFES Data Management System (DMS)

One of the major elements supporting the CAFES system and all CAFES subsystems is the Data Management System (DMS). While perhaps peripheral to the main flow of the CAFES operation, it provides baseline data for all models. DMS serves three purposes. First, it provides a unified system for storing, updating and retrieving all data needed by CAFES. Second, as the CAFES executive, it has an operating interface with all subsystems and is used in all models. Finally, it is under direct control of the analyst for use in either input or output of CAFES data.

The objectives of the data management system are a) to provide rapid access to standardized data relative to operational and/or proven system concepts for use by both the CAFES submodels and the HFE analyst, b) to allow for amalgamation of data commensurate with a given level of system definition in a rapid and easy manner, and c) to provide an information storage scheme sufficiently general to handle the diverse data requirements of the submodels. Major functions performed by the DMS are:

a) Data Input and Storage: Provides means to enter and file information into the computer, including input format, data addressing, storage allocation, etc.

b) File Modification: Provides means to add, delete, or substitute data in storage.

c) CAFES executive: Provides executive function to execute CAFES submodels, transfer data to and from files, generate reports, etc.

d) Error Diagnostics: Provides means for determining and reporting the cause of output errors and run interruptions.

e) Report Generation: Provides means for retrieving information from the computer, including report type (e.g., tabular or graphical), report format, labeling, etc.

CAFES Function Allocation Model (FAM)

The FAM is a collection of computerized algorithms that will, in conjunction with the DMS and HFE analyst, derive and process various alternatives for allocating functions to operators or equipment. The general objectives of the FAM are to identify and organize system functions to an allocatable level, and to identify and to rank order function allocation schemes (by performance effectiveness) that satisfy mission requirements.

The FAM works from a user-specified list of system functions, performance data and allocation candidates in an iterative process; a) to predict overall system effectiveness (probability of mission success) and b) to generate crew operational procedures for detailed evaluation of promising allocation candidates. Use of the FAM for evaluating allocation candidates is straightforward. For the initial application on a proposed aircraft system, the HFE analyst extracts, modifies, and assembles system functions. To the extent that functions are similar to those contained in the DMS, a primary data file can be rapidly assembled and structured. If the FAM or other CAFES submodel has been used previously on the particular aircraft system, data may be available also from these, e.g.: the Workload Assessment Model (WAM) for function allocation processing. The FAM output is checked by the HFE analyst for consistency with system requirements. If allocations are consistent, the user modifies the FAM input data and reruns FAM. The major FAM functions are:

a) Mission Evaluator: Computes probability of overall mission success for various function allocation candidates. Success probabilities for specific mission objectives can also be computed.

b) Procedure Generator: Derives data for use with operational sequence diagrams and procedure statistics based on function allocations, task priorities, procedure constraints, etc.

Given preliminary functions allocation candidates, the task/workload process described later is applied to appraise needs for reallocation and refinement. System effectiveness is predicted on the basis of operator and machine performance in terms of task error rates and task execution times. Operational procedures are derived according to user specified rules and constraints on the mission tasks. From FAM outputs, operational sequence diagrams can be constructed for selected allocation schemes. Table 3.9-1 indicates the applications or outputs of FAM.

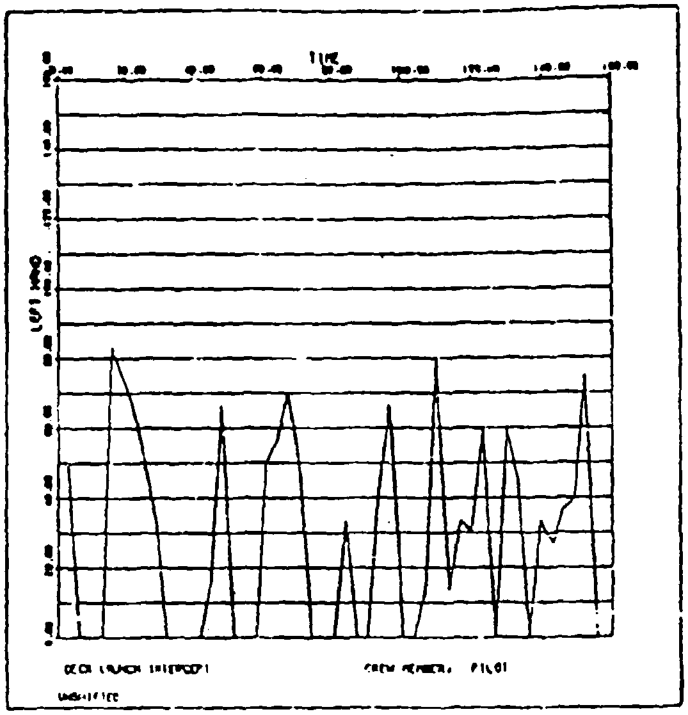
CAFES Workload Assessment Model (WAM)

The WAM considers the human performance aspect of man-machine function allocation schemes on a time and cumulative task basis to determine whether man can perform all of the tasks derived from the allocated functions. The submodel uses a timeline of mission tasks and determines those periods when man is overloaded in terms of time available versus time required to do all tasks, indicating the necessity for a) task rescheduling, b) reallocation of the function (or portions of it) to equipment or additional crew, or c) modification of the system requirements. Workload can be analyzed for each operator in a crew to determine how changes in task allocations will alleviate overloading conditions.

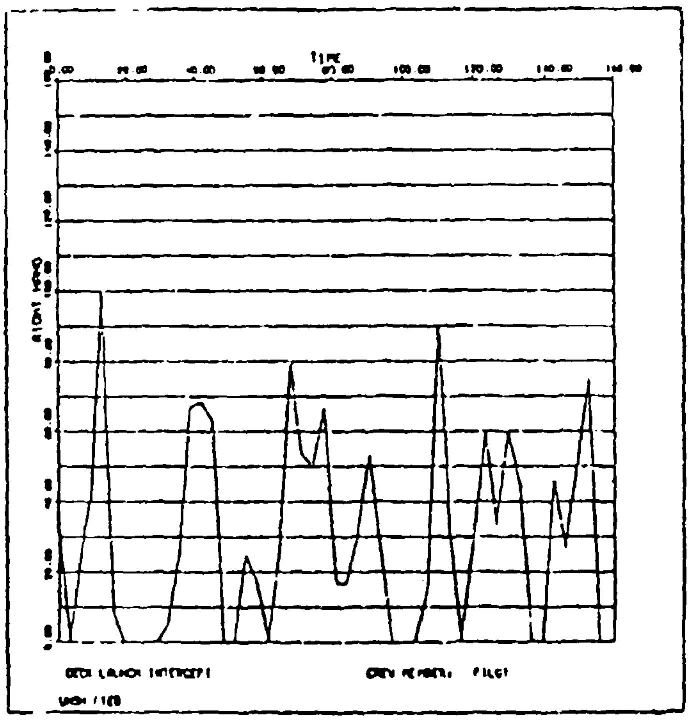
WAM is based on workload variations in each performance channel (e.g., eyes, hands, feet). WAM generates bargraph and histogram plots of workload data for use by the HFE analyst so that results may then be visually scanned to find heavy workload situations. If possible, task scheduling can then be moved to other time periods to reduce excessive workload. WAM also provides an option for automatically shifting tasks to equalize workload. Figure 3.9-17 illustrates samples of WAM histogram outputs. Table 3.9-1 indicates the applications or outputs of WAM.

3.9.4.15 SAINT

SAINT (Systems Analysis of Integrated Networks of Tasks) is a computer-aided technique that is useful for analysis of task/activity networks (Ref. 41, Wortman, 1977). SAINT has been developed by the Air Force Aerospace Medical Research Lab along with Purdue University and Pritsker and Associates. It is a modeling and simulation technique developed to assist in the design and analysis of complex man-machine systems. SAINT consists of a symbol set for modeling systems and a computer program for analyzing such models. SAINT provides the conceptual framework for representing systems that consist of discrete task elements, continuous state variables, and interactions between them. While SAINT was designed for modeling manned systems in which human performance is a major concern, it is potentially applicable to a broad class of systems- those in which discrete and continuous elements are to be portrayed and quantified and whose behavior exhibits time-varying properties. SAINT provides a mechanism for describing these dynamics so a systematic assessment can be made of the relative contribution system components made to overall system performance.



LEFT HAND



RIGHT HAND

Figure 3.9-17: Sample WAM Hand Workload Histograms

Systems are created as graphical networks of task activities with which one or more operators interact. Each task in a network is described as to now its performance affects the overall system and how it is related to other tasks within the system. The graphical operator/task analysis system description is entered into the SAINT computer program for automated performance assessment. Employing Monte Carlo techniques, SAINT permits the simulation of probabilistic and conditional task performance descriptions and precedence relationships. It also permits the collection of statistical estimates of system performance. Another major capability of the program is the system characteristics in response to system-internal or external simulated events.

By design, the SAINT technique does not require the user to perform any computer programming although experience in this field is extremely helpful. Users are assumed to be knowledgeable of task analysis. The results of a task analysis are used as the inputs to the SAINT computer program. The output of SAINT consists of task and mission performance estimates.

3.9.4.16 TLA-1

The acronym TLA-1 derives from "Time Line Analysis program - model one". It is generally referred to as TLA-1 rather than the complete descriptive title. As its complete title indicates, TLA is a time line analysis model. It is also used for workload analysis in a manner similar to the workload techniques presented in this section. It is strongly oriented towards cockpit analysis although it is easily adaptable to any crew station.

The TLA-1 computer-aided analysis technique is initiated by the preparation of scenarios and crew task data. The HFE analyst generates scenario data from sources such as flight plans, aircraft performance data, and aircraft operations manuals. If the analysis is for a completely new aircraft, the data must come from existing similar aircraft. Since operator tasks are the basic work units from which all TLA-1 crew workload statistics are derived, they must be identified for every control, display, and communication link. It is possible to catalog over 2,000 tasks for one analysis effort. The tasks are categorized by aircraft subsystems. Each task description contains a task code number, a task description/name, task duration time and the channel activity (left hand, right hand, external vision, internal vision, cognition, etc.).

After the scenarios and tasks have been defined, the analyst develops the detailed task sequence required to execute the scenario. Worksheets are used for this detailing. In the process of filling in the details on the worksheet, the HFE analyst specifies all the data that will be entered onto the various input data coding forms.

The next step is the input data coding. Each of the six sets of input data has a fixed-format coding form that the analyst uses. These data coding forms are for subsystems data, task data, events/procedures, phase data, mission data, and output report and plot request coding.

One of the most powerful features of TLA-1 is the wide variety of workload analysis data formats that are available. There are six digital reports and four data

plots that can be requested. By specifying various variables for each of these output formats, there are literally thousands of data records that can be selected for output for a mission. Obviously, not every conceivable report and plot will be requested at any one time.

Standard sets of reports and plots have been defined that can be specified by number. The items in these standard report sets have been selected to provide a general visibility of the workload situation for a scenario. As high workload problems are isolated, the analyst can be more selective of the output types and exercise tighter control over the variables so that successive data outputs can expose the nature of the workload problems in more detail.

The TLA-1 computer program is divided into the executive, input, processor, and output modules. The executive module processes all control cards and initiates the other three modules. All mission data are input through the input module and output to an external permanent file. The processor performs all the calculation functions and outputs the results to an external file. The input to the processor comes from the data stored by the input module. The output module inputs report requests and acts to produce the requested reports using the data from the two external files created by the input module and the processor module. There may be up to three sets of external files (different configurations of the same mission) input to create some reports. Outputs from the

TLA-1 program are to tape, printer, and plotter. A tape is used to store the mission data input and the processed data for later use by the report generation function. The tape consists of two files. The first contains the mission data input. The second contains the processor output used by the report generator function.

The output to the printer consists of seven reports:

a) Mission Scenario

b) Crewman Workload Profile

c) Crewman Workload Summary Statistics

d) Task Channel Activity

e) Subsystem Activity

f) Subsystem Activity Summary

g) Task List

The plotter output consists of a workload summary, a channel activity summary, a workload histogram, and a mission timeline. Figure 3.9-18 is a sample channel activity summary and Figure 3.9-19 a sample workload histogram plot.

Table 3.9-1 indicates the applications or outputs of TLA-1 compared to the outputs of other analysis techniques. Additional information on TLA-1 is available in Reference 42 (Miller, 1976).

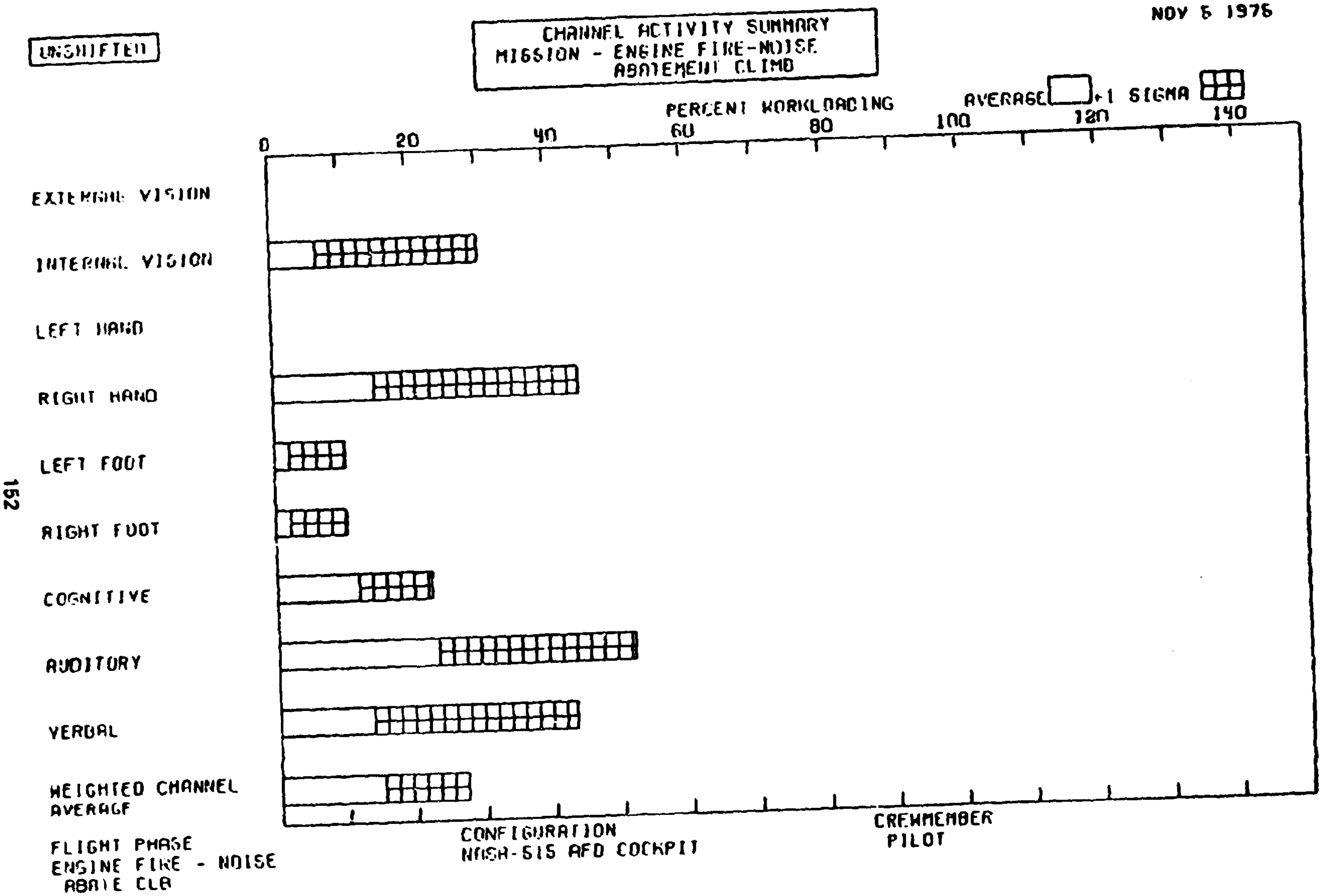


Figure 3.9-18: Sample TLA-1 Channel Activity Summary

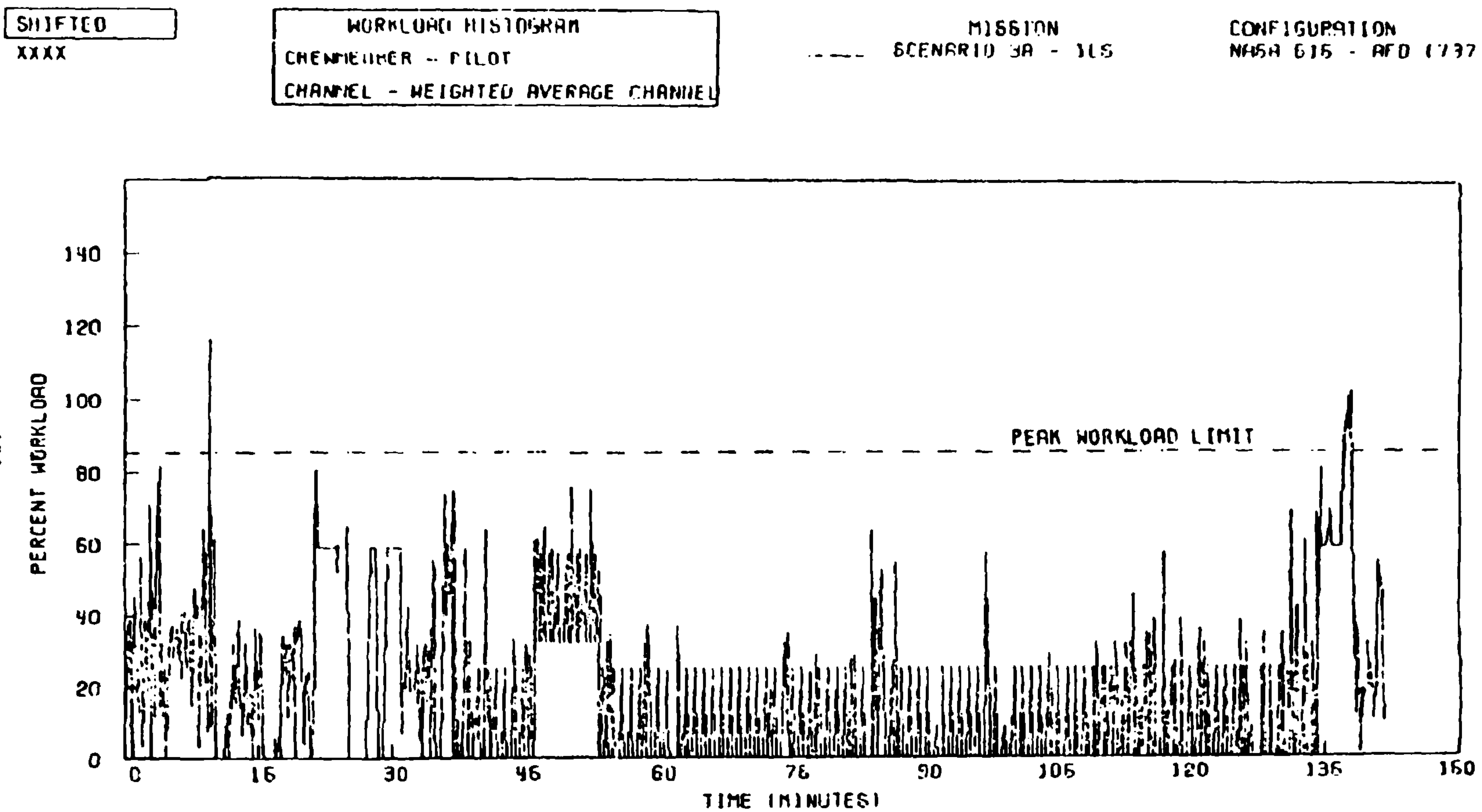


Figure 3.9-19: Sample TLA-I Workload Histogram Plot

3.9.5 Design

The purpose of this activity is to provide a system man-machine design which incorporates all necessary HE design criteria. The man-machine interface design is not limited to portions of system equipment, but includes software design, procedures, work environments, and facilities associated with the system functions requiring personnel interaction. This activity is accomplished by converting the results of the analysis activity into HE and Biomedical design criteria. It is heavily dependent on the selection of applicable MIL-STD-1472 design criteria.

In order to develop and/or apply appropriate HE design criteria to the system design, a concerted HE design effort must be accomplished. Many of the most useful design aids, tools, or techniques which are appropriate for use of HE are presented in the following sections. Depending on the nature of the program, only a portion of them would normally be used. Sufficient time or HE effort does not exist to use all of the techniques for a single program. Much of the data presented are also organized into tabular form in Table 3.9-7. By listing the techniques in one chart they may be easily compared for possible selection and use. Reference 43 (Roebuck, 1975) provides additional information of several of the design techniques and tools including vision plots, reach envelopes, mockups, and manikins.

Table 3.9-7. Design Techniques Selection Chart

	Selection evaluation characteristics: Most applicable program phase				Relative complexity			Relative time to perform			Relative cost (~man-years)			Relative cost effectiveness		
Alternative techniques	Conceptual	Validation	FSD	Prod/deployment	Simple	Average	Complex	Short	Medium	Long	Low	Medium	High	Low	Medium	High
1 Design criteria checklist		X	X	X	X			X	X			X				X
2 Drawings	X	X	X	X		X			X			X			X	
3 Vision plots	X	X				X			X			X			X	
4 Reach envelopes	X	X				X			X			X			X	
5 Mockups	X	X	X			X			X	X		X	X		X	X
6 Models	X	X				X			X		X	X		X	X	
7 Manikins	X	X	X			X			X		X				X	X
8 Specifications		X	X	X	X	X			X	X		X			X	
9 CAFES (CAD, CGE)	X	X	X				X			X			X		X	
10 HECAD	X	X	X				X			X			X		X	
11 COMBIMAN	X	X	X				X			X			X		X	
12 CAPE	X	X	X				X			X			X		X	

3.9.5.1 Design Criteria Checklist

Description: The checklist is a series of equipment and facilities design requirements of criteria taken from human engineering standards, e.g., MIL-STD-1472, handbooks and guides. Often, during the early stages of a program, a checklist is developed by HF engineers for that particular program. Design criteria which would be applicable to the particular program are extracted from the various standards and handbooks and listed in a program unique checklist. The checklist may be divided up into sections or categories of design criteria corresponding to major equipment or facilities characteristics. These categories might be visual displays, audio displays, controls, etc. The checklists generally have a space to the right of each listed item of design criteria. This space is divided into three columns: compliance, noncompliance, and not applicable. Figure 3.9-20 is a sample page from the checklist.

Procedure: The HFE evaluator reads the item of criteria, observes the item of hardware (or mockup or drawing), and checks the appropriate space for applicability and compliance. Many checklists provide additional space to include comments as to the reason for noncompliance or other remarks appropriate to the listed design criteria item.

The HFE evaluator should initiate the use of the checklist with at least some knowledge of the purpose or function of the design item being evaluated. He must have a good working knowledge of the checklist criteria which he will be using. He should determine if the item of hardware has had any previous checklists completed on it, even if the hardware was only in drawing form at the time. The more formal test and evaluation procedure will occur when the item being

MIL-STD-1472	COMPLIANCE			COMMENTS & DISPOSITION
	YES	NO	N/A	
5.1.2.1.1.2 <u>Access</u>.- Providing that the integrity of grouping by function and sequence is not compromised, the more frequently used groups and the most important groups should be located in areas of easiest access. Control-display groups required solely for maintenance purposes shall be located in a position providing a lesser degree of access relative to operating groups.				
5.1.2.1.1.3 <u>Designation</u>.- Functional groups may be set apart by outlining with contrasting lines. Where such coding is specified by the procuring activity, and where gray panels are used, noncritical functional groups (i.e., those not associated with emergency operations) shall be outlined with a 1/16-inch (1.6mm) black border (27038 of FED-STD-595), and those involving emergency or extremely critical operations shall be outlined with a 3/16-inch (4.8mm) red border (21136 of FED-STD-595). As an alternate method, contrasting color pads or patches may be used to designate both critical and noncritical functional areas, subject to prior approval by the procuring activity. When red compartment lighting is used, an orange-yellow (23538 of FED-STD-595) and black (27038 of FED-STD-595) striped border shall be used to outline functional groups involving emergency or extremely critical operations. Critical and noncritical control-display areas in aircraft crew stations shall be delineated in accordance with MIL-M-18012.				
5.1.2.1.1.4 <u>Consistency</u>.- Location of recurring functional groups and individual items shall be similar from panel to panel.				
5.1.2.2 <u>Location and Arrangement</u>.- Whenever an operator must use a large number of controls and displays, their location and arrangement shall be designed to aid him in determining which controls are used with which displays, which equipment component each control affects, and which equipment component each display describes.				
5.1.2.3 Arrangement Within Groups.- Controls and displays within functional groups shall be located according to operational sequence or function, or both.				
5.1.2.3.1 Left-to-Right Arrangement.- If controls must be arranged in fewer rows than displays, controls affecting the top row of displays shall be positioned at the far left; controls affecting the second row of displays shall be placed immediately to the right of these, etc.				
5.1.2.3.2 <u>Vertical and Horizontal Arrays</u>.- If a horizontal row of displays must be associated with a vertical column of controls or vice versa, the farthest left item in the horizontal array shall correspond to the top item in the vertical array, etc. However, this type of arrangement shall be avoided whenever possible.				

Figure 3.9-20: Sample MIL-STD-1472 Checklist Page

evaluated is at least in the prototype hardware stage of development. Less formal checklist test and evaluation may take place with hardware drawings or possibly mockups. In any case, the evaluation should take place on a noninterference basis, i.e., the gathering of the checklist data should not interfere with the conduct of any other test aspects. The use of the checklist is essentially a static operation, as opposed to a dynamic test which requires observation of operators performing their tasks and equipment properly responding to their manipulation.

The checklist evaluation will result in a verification of the fact that the design item meets all pertinent HE design criteria. If some design criterion is found not in proper compliance, then this information will be provided to design engineering personnel. In some situations, there may be satisfactory rationale as to why an item of hardware does not or should not meet the HE design requirements. In this case, a request for deviation to HE design criteria may be submitted to the Air Force system program office for their approval.

Use/Validity: This technique is used more often than any other to evaluate design hardware. It is an excellent way to gather quickly qualitative data on system hardware components. However, in order to be of real value, there must be considerable detail contained within the checklist. Depending upon how the checklist is structured, the amount of detail required for review can extend the time required to perform the checklist. Use of the checklist requires more knowledge of basic HE design criteria than system performance requirements.

The disadvantages associated with the use of the checklists are that they produce binary data; the design criteria being verified is either in compliance or not. However, many criteria items have the potential for an exact quantitative evaluation; thus considerable data will be unrecorded. The checklist is used for evaluation of hardware only. In its present, generally agreed-to formats, the checklist will not evaluate personnel skills, quantities, training, technical publications, etc.

The use of this particular technique is strongly advised for both design and T&E program activities. If not used, there is significant risk that lack of critical design compliance requirements will be overlooked.

3.9.5.2 Drawings

Description: Engineering sketches and drawings are precise outline drawings (usually void of shading) used to provide information as to the design of the item, facility, or subassembly which is a component or part of the total system. By a logical procedure of depicting related drawing "views", intricate and complicated shapes are clearly shown. Exact and detailed sizes are provided without ambiguity. Individual parts are identified for assembly and are located in the assembly in their correct functional position. In addition, descriptive notes provide information as to materials, finishes, and directions for manufacture and assembly.

Often engineering drawings are referred to as sketches. This is only because of their intended lack of contractor or customer sign-off approval. They are in every other respect similar to engineering drawings. Engineering drawings or

sketches of interest to HE personnel may be further categorized as hardware drawings, workspace layout drawings, console drawings, and panel drawings. Console drawings, in particular, should contain information as to the man-machine interface, for example, the seat reference point (SRP) and eye reference point (ERP) should be indicated. Interface control drawings (ICD's) are another type of drawing that should require HE review. As their name implies, these drawings are used to describe and to eventually control proposed interfaces between components, subsystems, or different contractor's equipment items. Vision plots (Ref. Figure 3.9-21) and reach envelopes (Ref. Figure 3.9-22) are two additional types of drawings of particular interest to HE.

Procedure: Generally, engineering drawings are used by HE personnel to review the design concepts. However, the HE group may actually prepare engineering drawings for their own use and the use of others. The development of engineering drawings by HE are predicated on the data necessary to initiate the drawings including the drawing equipment and the skills of engineers, draftsmen, or industrial designers.

The preparation of workspace layout drawings requires skill in descriptive geometry. The HE analyst must be able to project views and cross sections of the workspace geometry and the human subject into various auxiliary planes which often are not parallel to the normal planes of the three-view or the graphic engineering drawings. Also, for purposes of visual clarity and understanding, perspective drawing techniques should be understood and used. The ability to mentally visualize the geometry of workspace layouts and to accurately prepare drawings depicting the interface relationships can save time and effort during mockup studies.

More normally, HE personnel use engineering drawings developed by project design personnel. They must, of course, be sufficiently knowledgeable of standard (Air Force and contractor) drawing practices to understand the information being presented. HE design criteria checklists (Ref. Figure 3.9-20) may be used along with fractional scale plastic manikins to insure the HE adequacy of the design. Once this adequacy is assured, the drawings should be signed-off to indicate HE design application approval.

Use/Validity: [illegible] specialists have prepared the engineering drawings, it [illegible] assured that the drawings incorporate all appropriate HE design criteria and that HE sign-off (as discussed in Section 3.4.1) is automatically provided. If the drawings are prepared by other project engineering personnel, HE should thoroughly review them to insure the inclusion of appropriate HE design criteria. The MIL-STD-1472 checklist should be used at this time. Completion of the checklist will provide justification for HE sign-off (or lack of same) for the drawings.

In addition to HE design verification, engineering sketches and drawings specify the detailed design of the hardware item. They provide a baseline configuration record (Ref. Sections 3.3.1.3 and 3.9.8), they provide inputs to initiate mockup construction, and they provide manufacturing with the necessary data from which to produce the hardware product.

3.9.5.3 Visibility Diagram

Description: The vision plot or visibility diagram is a special drawing to show the vision envelope of specific system operators. An analysis of their vision envelope capabilities can be provided by multiple views of the operator in front of the console or other instruments and controls. However, rather than showing the side, top, and/or front views, the visibility diagram shows the actual view from the operator's eye (eye reference point, ERP). Figure 3.9-21 is a sample cockpit visibility diagram. As can be seen from this diagram, the envelope is a plot of angles both to the left and right of the operator's sagittal plane (directly forward) and up and down from the horizontal plane through the ERP.

Procedure: Visibility diagrams are developed in accordance with specific procedures such as those detailed in MIL-STD-850 (Ref. 44). The HE analyst or draftsman preparing the drawings works from the two or three view orthographic drawings of the operator work station (e.g., flight deck or cockpit). Through descriptive geometry techniques, he measures the angles from the ERP to significant items shown in the orthographic drawings. Windows, instruments or controls are generally the primary items of interest in the visibility diagrams. The angles to several points on each of the significant items are measured and plotted in order to approximate the shape of the item. All straight lines shown on the orthographic projection (with the exception of vertical lines and lines within the horizontal plane through ERP) will be plotted as curved lines. Straight lines below the horizontal plane will curve up, and above the plane will curve down.

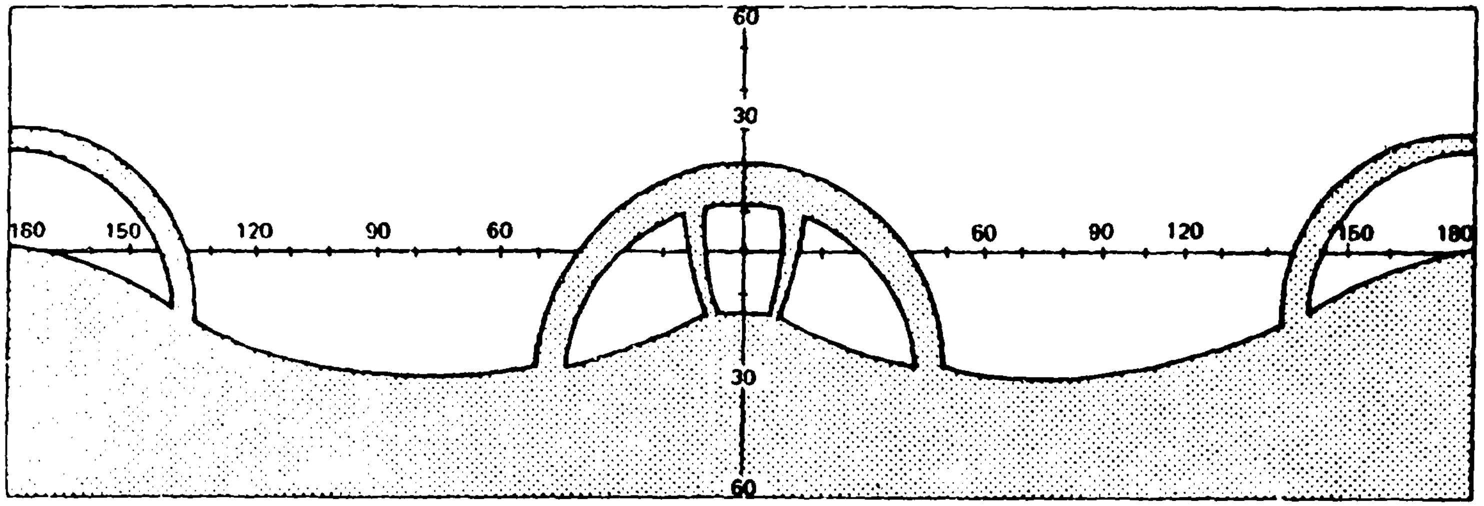


Figure 3.9-21. Sample Cockpit Visibility Diagram

Use/Validity: Visibility envelopes are useful to determine what operators can and cannot see. Their use in cockpit or flight deck design is extremely critical to determine where window posts are located in reference to the pilot's runway vision at various landing approach geometries. Whereas new aircraft design aerodynamic considerations tend to dictate flat angle smooth surfaces around the aircraft cockpit area, these considerations cannot violate the pilot's minimum vision requirements as described in military and FAA specifications. The visibility diagram provides a technique for making the specification comparison. It further provides a record of the system design and generally avoids the cost of preliminary mockups which would otherwise be constructed just to evaluate operator vision.

3.9.5.4 Reach Envelopes

Reach envelope drawings describe the envelope within which controls must be placed in order to be successfully reached by the subject operator. Until recently, the operator has generally been described as one with a 5th percentile functional reach. Recent bimodel male-female populations may not include sufficient data to calculate the lower limit percentile for determining the desired reach envelope. The envelopes vary greatly for the 5th percentile operator for known male populations. This is because of variations of seat design and shoulder and lap constraints if the operator subject is seated. Reach envelopes are also developed and used for overhead reach.

The procedure for developing reach envelopes is simply to modify or adapt existing data or to develop new data. Functional reach is always the parameter of main interest. Measurements are made with the subject's thumb and forefinger tips pressed together. Secondary parameters such as shoulder height are also of interest and combine with functional reach to provide the total reach envelope data.

Information showing appropriate combined reach data are available in DH 1-3 and a few other sources. If, because of peculiarities in the particular new system seat and the operator restraint system, it is not possible to use previously developed data, then new data can be developed. This will require the gathering of appropriate size and number of subjects to match the population and the seat to be used in the new system. Reach capability data must be taken for each of the subjects under various conditions, such as a pressure suit, seat back angle, and shoulder restraint, and in various directions and heights in relation to the seat reference point (SRP) or ground reference plane. Once the data are obtained, statistical distributions of reach data may be plotted and a percentile curve or statistical estimate may be selected and prepared. The envelope drawings are then plotted and overlaid onto the console or cockpit drawings. The SRP or other hardware datum reference is necessary to establish where the reach envelope should be located. Examination of two or more different orthographic views of the control panel hardware, which are overlaid by the envelopes, will determine if the necessary controls are within the operator's reach or if the controls and operator must be moved closer together.

Reach envelope drawings are important to proper console design, particularly if the console is large with side wraparound panel areas or vertical panel areas which project above the eye reference point (ERP). Proper use of reach envelope drawings will save later mockup construction effort. Engineering drawings and sketches may be validated prior to the use of mockups and prototype hardware. If properly presented, reach envelopes may be easily understood by non-HE personnel and can be very useful as a part of hardware design review presentations. Figure 3.9-22 illustrates a sample reach envelope drawing.

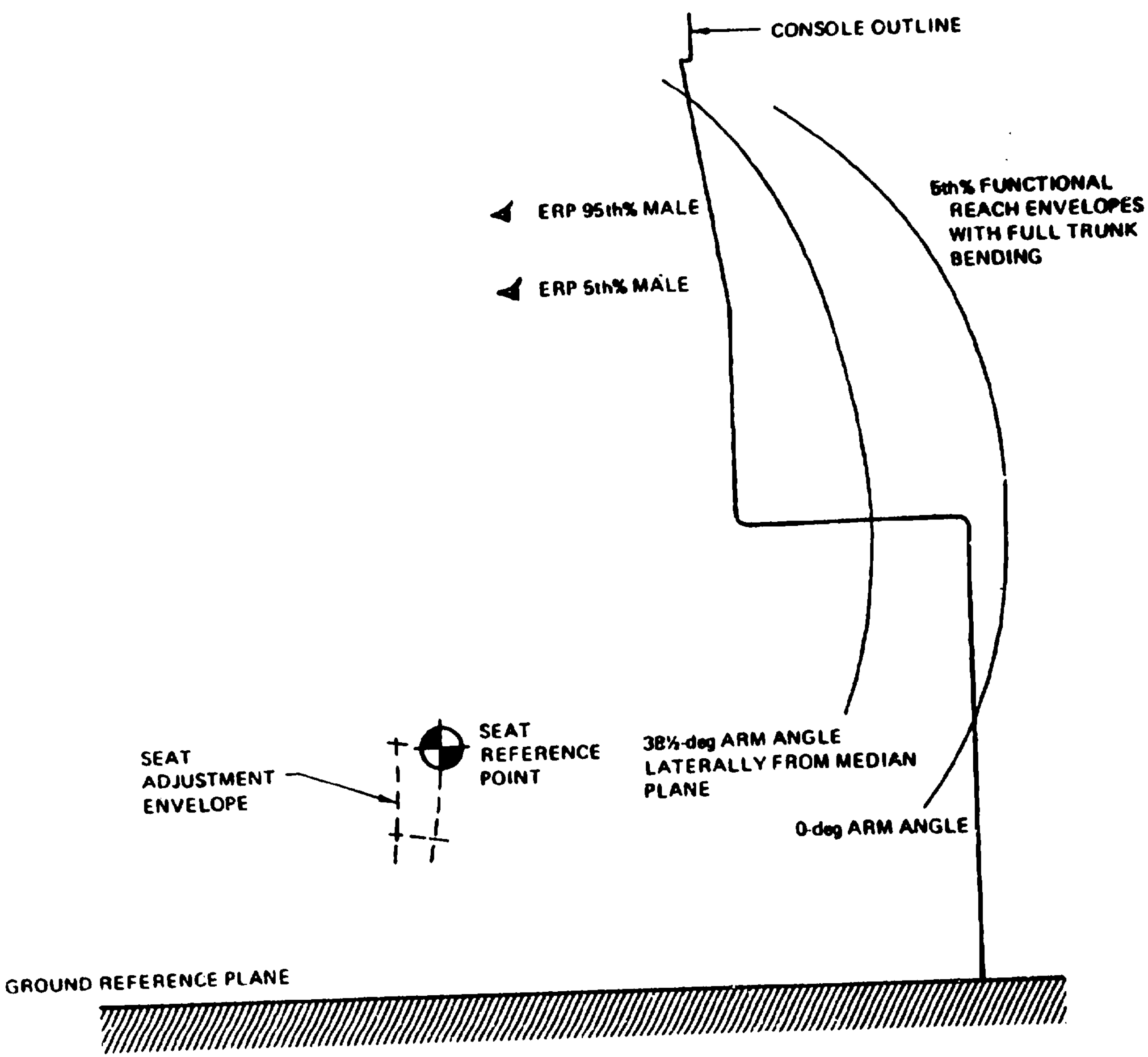


Figure 3.9-22. Sample Reach Envelope

3.9.5.5 Mockups

Description: Mockups should be constructed as a significant part of the development of the man-machine system. They should be considered as tools which are used to evaluate the system design before the actual manufacture of system hardware. Mockups are of two basic types: static and functional (or dynamic). The static mockup is a full scale model of an item of equipment or a facility. It is usually made of inexpensive materials such as cardboard with a foam core or plywood. All major internal components are represented as actual small items of hardware or by cutouts of drawings or photographs of the internal items. The external dimensions of the mockup are usually not critical. Internal dimensions having to do with workspace design, displays, and controls should be reasonably precise.

Functional mockups can operate in limited simulation of the prototype equipment. A functional mockup has controls and displays that actually work as compared to the nonoperating static mockup. The number and type of operations that may be provided in a functional mockup covers a wide range. The more complex functional mockups are little different from simulators.

Procedure: The mockups should be made initially with the easiest to use and cheapest material possible. Various thickness plastic foam core filled cardboard sheets may be used quite easily with a hot glue gun and a sharp matte knife to build consoles, racks, and even complete cockpits. Console panel layout drawings may be simply glued to the foam core cardboard to simulate the appropriately located displays and controls. Test participants or evaluators may simulate the observation of displays or actuation of controls by simply touching the drawing and performing the appropriate hand (foot) motion. As the system design progresses and mockup

tolerances become more critical, plywood material should be used. Plywood is both more rigid and durable, although considerably more costly in terms of construction costs. The plywood mockups may be converted from a static representation of the system to a dynamic or hot mockup, also referred to as functional mockups. The console panel drawings which were glued to the plywood may be replaced by the actual displays and controls.

Use/Validity: Wiring, cabling, piping, and ducting may be designed to visualize three-dimensional problems from scaled down, two-dimensional drawings. Measurement of operator/maintainer subject reach capabilities, clearance spaces, access opening, and vision envelopes can be determined and compared with the system design requirements for verification. Photographs and motion pictures may be made to provide coordination aids and maintain records.

It is cheaper to develop a static mockup or even a functional hot mockup, which includes the proposed electrical wiring, than it is to build prototype hardware with numerous design errors. A functional mockup makes it possible to study the performance of personnel in simulated operational situations. The HE specialist can thereby evaluate operational characteristics of equipment in terms of human performance. More realistic lighting and sound measurements may be taken. Procedures may be verified. Test participants may be observed and interviewed with a much greater degree of confidence as to the validity of their responses. In addition to all of the above, mockups along with photographs and movies provide an aide to design presentation reviews and, later on, to training system development.

3.9.5.6 Models

Occasionally, when the fabrication of full scale mockups of hardware or facilities would be too elaborate or expensive to construct, scale models are used in their place. Unfortunately, the use of scale models negates much of the value for HE because of the lack of good HE evaluation tools such as three-dimensional scale model manikins. Models are more easily transported and stored than mockups. Models are useful to perform some logistics analyses, but cannot be well used to perform, for example, MIL-STD-1472 checklists (Ref. Figure 3.9-20).

3.9.5.7 Manikins

A tool useful for evaluation of engineering drawings and sketches is the two-dimensional articulated plexiglas manikin. A set of these manikins may be obtained or prepared in a range of sizes and scales for use by HE or project design groups. They are usually made to represent two-dimensional anthropometric aspects of humans as seen from the side. For maximum flexibility, a large number of sizes, shapes, and scales which correspond with engineering drawing practices, (e.g., 1/10 and 1/4 scale) will be required.

The manikins are used by placing them in the workspace positions indicated on the drawings and articulating the figures to various reasonable positions to check for conditions of interference, access, or reach availability. To a limited extent, visual envelopes may be checked. If the required percentile population of users is known, e.g., 5th through 95th percentile, then the manikins should be used to check to determine if the design is compatible with each of the anthropometric parameters represented by the 5th and 95th percentile manikins.

Because the manikins are made of clear plastic, it is easy to see the amount of interference of overlap if the manikin's dimensions exceed the space provided on the scaled drawing.

Frequently, the manikins may be used by engineers or draftsmen to illustrate a drawing with sketches of various sized personnel in various critical positions. The manikins are used as a template around which the engineer or draftsman would draw the outline of the properly scaled person in the desired articulated position on the drawing.

The use of these manikins is most worthwhile during drawing preparation and evaluation. Whereas the cost of the manikin procurement (in terms of a full set of sizes and shapes) is several hundred dollars, they tend to save this expenditure by the proper initial design of mockups and prototype hardware rather than the costly redesign of the same. The manikins do have limitations in that they cannot possibly be completely and properly articulated. As with any type of manikin, they represent a theoretical person and they are useful for determining compliance with only one anthropometric parameter at a time. MIL-STD-1472 requires compliance with ninety percent of the population. Given the population, it is essentially impossible to design a manikin or manikins which guarantees the use of ninety percent of the population. To compound the problem, new user populations include females. This makes it most difficult to define what the combined male-female population is. The percentages of male and female are not equal and the shape of the bimodal population curve is undetermined (Ref. Section 3.9.6, Statistical Analysis). The manikins are therefore only a very approximate tool. They cannot be used by themselves to determine precise design compliance or deviation from criteria.

Other forms of manikins have been developed for full scale use in aircraft escape systems and other similar hazardous use. Their use is more appropriate to the test and evaluation phase of HE rather than the design phase.

3.9.5.8 Specifications

One of the most important methods to use in insuring the adequacy of HE design in the system is to include applicable HE design criteria in the hardware specification. Whereas the overall need for this HE task is presented in Paragraphs 3.1.3 and 3.6.1, it is the job of the HE specialist to insure that applicable HE design criteria is incorporated into each appropriate hardware item specification. Generally, it is easiest and safest (in spite of the need for tailoring) to call out all of MIL-STD-1472 as a requirement for each hardware specification.

All major hardware items which make up the total system require individual specifications. In accordance with MIL-STD-490, which describes how to prepare a specification, Paragraph 3.3.7 of the specification should be used to describe the requirements for human performance and HE.

3.9.5.9 CAFES Computer-Aided Design (CAD)

One of the HFE analyst's or crewstation designers' jobs is to produce crewstation configurations that are consistent with mission requirements, constrained by military design standards and specifications, and compatible with technical and cost considerations. The computer-aided design submodel enhances the analyst's capability to integrate all the diverse design considerations into a workable configuration.

An overview of CAD capabilities is illustrated in Figure 3.9-23. CAD functions include: a) geometry description for computer storage/retrieval; b) proportionate scaling (expansion/contracting) of defined crewstation geometry; c) customized changes (tailoring) in geometry of computer-stored configurations; d) interference analysis between crewmember escape and a specified crewstation; e) vision analysis; f) reach analysis; and g) computer-generated graphic views of crewstation cross sections.

The major CAD functions are classified under three categories:

a) Crewstation Design Development: Provides means for computer storage of crewstation configurations by scaling, tailoring, repositioning, or rearranging specified subsystems.
b) Crewstation Design Analysis: Computes metrics for reach, vision, and escape analysis as a function of configuration design and crew member size.
c) Graphic Functions: Provides graphical output of crewstation designs and design analysis in hard copy. Provides for growth to include interactive graphics modes. Graphic data outputs can include sectional views, perspectives, and production drawings.

Table 3.9-2 indicates the applications or outputs of CAD. References 39 and 40 contain a more complete description of this technique.

CAFES Crewstation Geometry Evaluation (CGE)

The Crewstation Geometry Evaluation program was an experimental development by Boeing and JANAIR to establish a standardized method for evaluating the physical geometry of a crewstation.

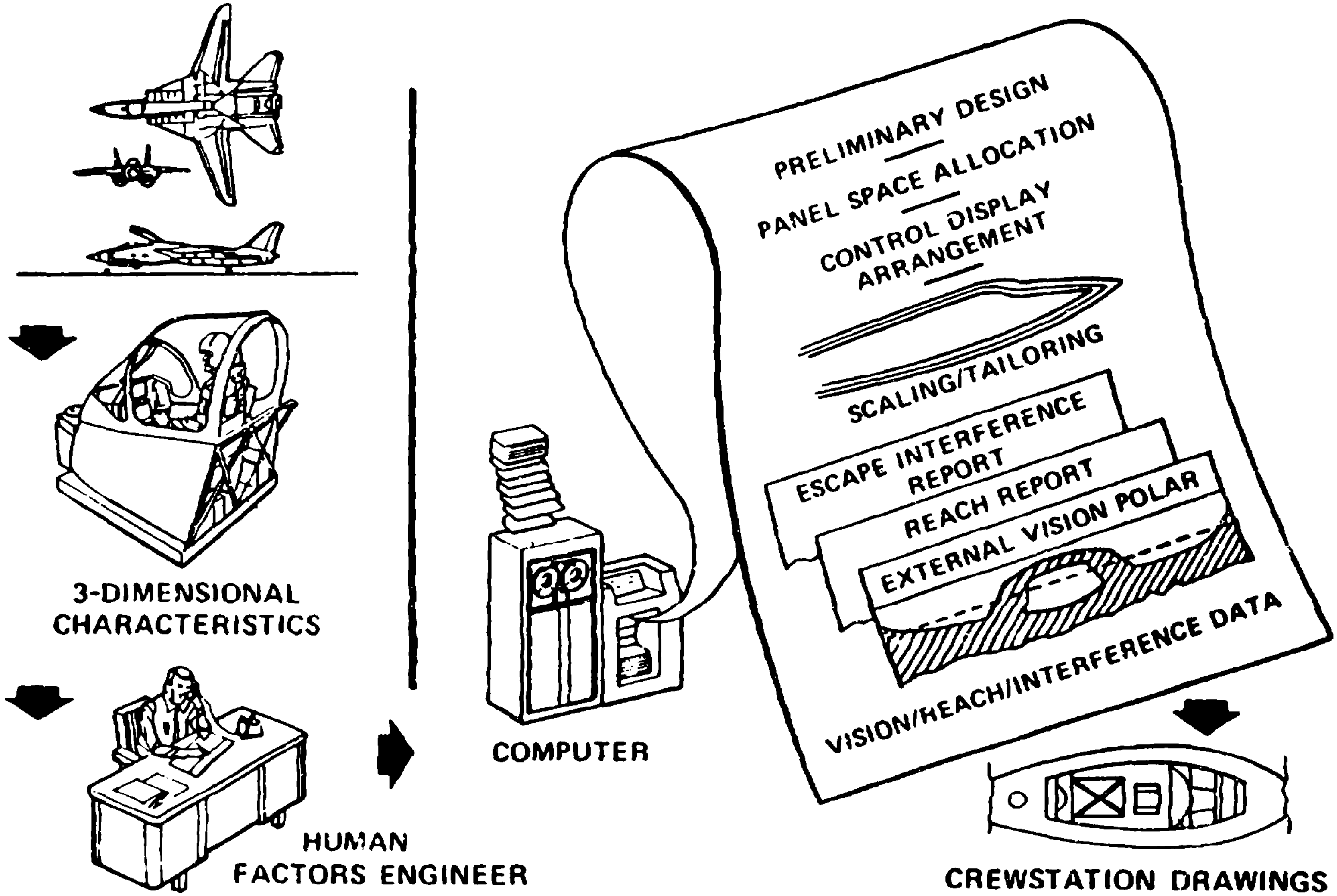


Figure 3.9-23:CAFES Computer Aided Design (CAD)

It evaluates the physical compatibility of a seated crewmember of any size with any crewstation based on a specific crewstation design. Data on the crewstation geometry and the sequence of tasks to be performed are stored in a data file. Mathematical routines provide dynamic movement for a variable-sized mathematical man-model. Numerical indicators (hand/joint travel), physical and visual interferences, and reach infeasibilities are output. The crewstation compliance with certain military standards and specifications (e.g. MIL-STD-1333, Ref. 45) requirements are also checked. The general process is depicted in Figure 3.9-24.

CGE is a highly detailed component of the evaluation portion of the CAFES system. It takes the man-machine function allocation results of the FAM (as evaluated by workload analysis in the WAM), a detailed crewstation configuration design (as aided by the CAD), and selected crew anthropometry to evaluate the design with respect to potential geometric or physical problems. Anthropometric data reside in the CGE data file and crewstation and task sequence data are appended to it. Table 3.9-2 lists the applications or outputs of CGE.

3.9.5.10 Human Engineering Computer-Aided Design (HECAD)

HECAD is an interactive computer graphic program. It consists of two major parts. The first is the geometrical part with which a workspace designer can arrange control and display components into a workspace configuration. In the second part, a number of analyses are available for evaluating the arrangement of components against one or more crew station task sequence (Ref. 46, Topmiller, 1978).

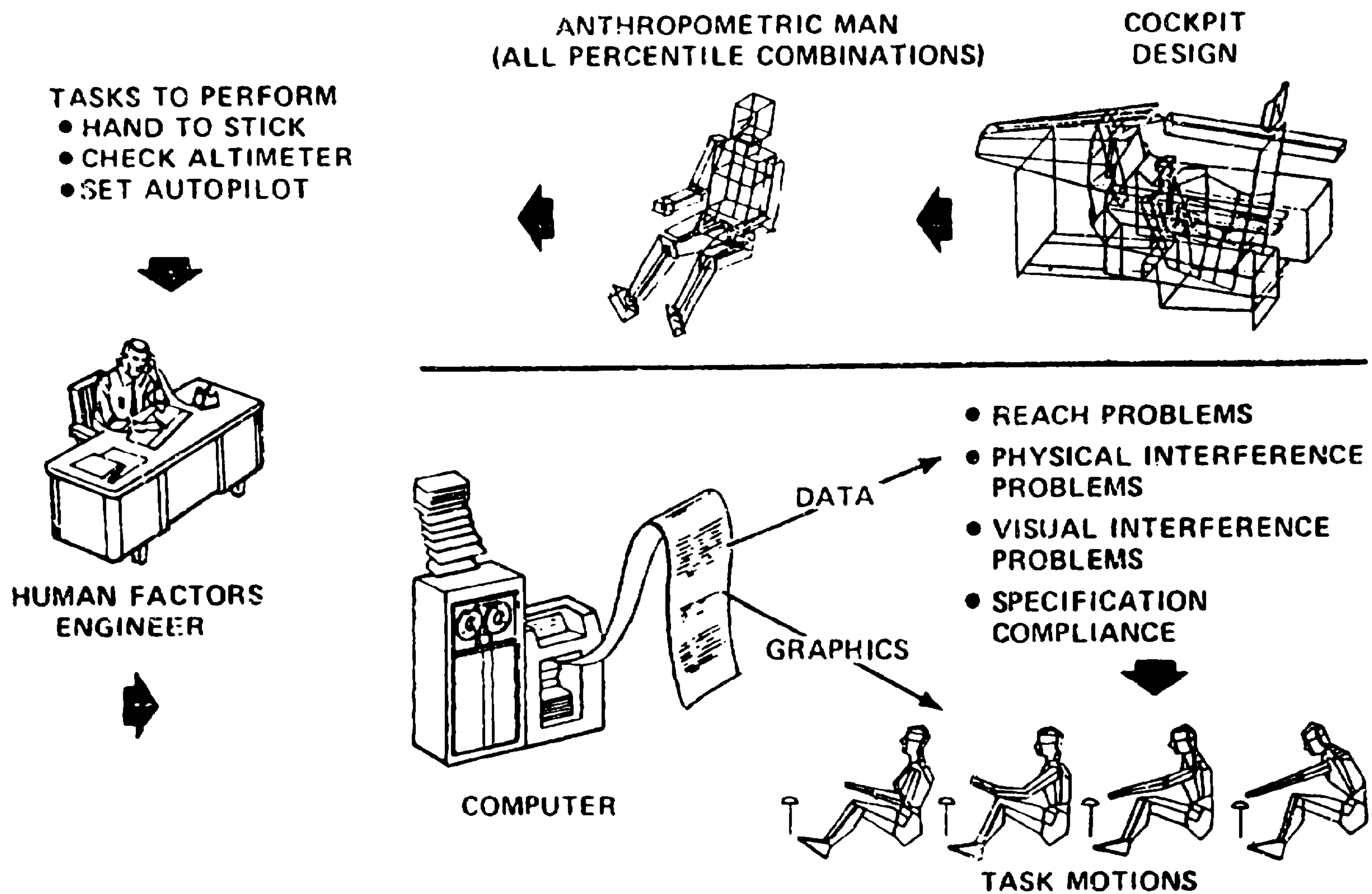


Figure 3.9-24:CAFES Crewstation Geometry Evaluation (CGE)

The program requires three main inputs: a set of data describing the components (name, size, type, activation time and activation reliability, and, optionally, coordinate information); one or more panels described by their corner coordinates; and one or more task sequences. This feature allows the designer to break an entire mission up into smaller and more manageable task sequences, such as preflight, takeoff, and landing. In the simplest form, the task sequence is a listing of the component identifying numbers, in the order that they are activated or visually scanned. There are also provisions for communication time and for machine time, when the operator acts on the machine and then the machine requires some reaction time (e.g., warm up).

The program presents, on a CRT, a perspective projection of the work station with panels represented by outlines and components represented by dots. The designer can select the point from which the projection is taken and change it at will. Everything is located in a set of orthogonal coordinates whose point of origin can be located anywhere in three-dimensional space.

Several analyses are available in the second, analytical part of the program. First, there is a basic reach analysis which determines the distance between a component and a shoulder reference point. The second available analysis is a visual presentation of fingertip paths during a task sequence. This analysis can be used to identify undesirable parts in the task sequence, such as unnecessarily long excursions or frequent reaches back and forth. Third, there is the task analysis. This analysis takes the indicated task sequence and examines the list of

components used in the sequence. The fourth analysis was developed because of the dissatisfaction with previous reliability computations. The main difference in task time calculations in this analysis is that the original program assumed a single, straight-through sequence of panel operations (called the dominant path) for accomplishing the task. This analysis introduces allowances for additions or deviations (called branches) from the dominant path.

Armed with the knowledge gained from all four of these analyses, the designer can decide what changes should be made in the configuration of the workplace. The computer does not order any changes; they are strictly up to the designer. The designer may have good reasons for locating a certain component in a certain place (the artifical horizon in an aircraft would be an example). Of course, the designer can also contemplate changing the order of actions if the equipment permits this.

With HECAD, a designer can assemble a workspace, execute various tasks on it, identify its potential design shortcomings and correct them, so that a prototype design is quite well polished before one tries simulation runs in a mockup, or other operator-in-the-loop simulation which is usually a time consuming and expensive process. However, there still is room to grow and to add some more capabilities. One of the considerations during the development of this model has been to assemble a procedure or design tool that is easy to understand and apply, requires a minimum of preparatory work, and quickly produces meaningful results: in other words, a technique that workspace designers would find desirable and useful, and one that is well human engineered.

3.9.5.11 Computerized Biomechanical Man-Model (COMBIMAN)

The Air Force Aerospace Medical Research Laboratory is developing a computerized biomechanical man-model called COMBIMAN. This on-line interactive computer model was conceived as a three-dimensional manikin for workplace design and evaluation. COMBIMAN has important applications in the evaluation of existing workplaces, design of new workplaces, selection of criteria for personnel to fit workplaces, and mapping visibility plots (Ref. 47, Evans, 1978).

Because a worker functions in three-dimensions, it is difficult to evaluate adequately a workplace from a two-dimensional drawing. While mockups provide a three-dimensional representation, construction of a good one is both time consuming and costly. The mockup evaluation is also limited, because it is difficult to find subject operators who adequately represent the anthropometric variability of the user population, a limitation which has led to erroneous conclusions. A mockup requires some cost and effort to modify. Thus, it can become an obstacle to design change.

COMBIMAN does not share these handicaps. It is a three-dimensional model which may be moved about and viewed from any angle. Since the man-model and workplace design exist only on a CRT display and in a computer memory, there is no significant investment of time or materials in effecting modifications. Because the user can modify the design easily while sitting at the display, the resistance to change is eliminated and experimentation is encouraged. Alternative designs may be thoroughly evaluated and then permanently recorded by means of a pictorial plot or tabular printout of the workplace data and man-model.

The variable geometry of the COMBIMAN allows the user to define quickly a series of man-models which represent the entire anthropometric range of a given user population. A variety of special problems can be evaluated by generating realistic ranges of certain body segments, while proportioning the remaining segments to achieve a reasonable configuration. With COMBIMAN, the operator can specify a certain sitting eye height and the program will generate a man-model with realistic proportions. The user is prevented from selecting an unrealistic combination of body-segment dimensions by constraining equations which are derived from the actual anthropometric data base of the population being considered.

The man-model itself is constructed in three stages. The first stage is the generation of the link system consisting of 33 segments which correspond functionally to the human skeletal system. The second stage is the definition of the enfleshment ellipsoids (a three-dimensional ellipse) about the link system joints. The third stage of man-model construction is connection of the ellipsoid silhouettes by tangent lines.

The two most important applications of COMBIMAN are in (a) the design of workplaces, and (b) the evaluation of workplaces. The other features of the model (variable anthropometry, reach envelopes, visibility plots, etc.) are used in support of these two primary applications.

The COMBIMAN is a valuable and powerful tool for assisting the engineer in the design of workplaces. Starting with a list of requirements for a workplace, the designer can call up the man-model to which he has been assigned dimensions representative of the population of intended operators. The

designer can then quickly define the various control/display panels around the man-model indicating the cornerpoints with the lightpen. These are then connected by lines to indicate the panels which are not only created on the display, but are also entered in the three-dimensional storage arrays and can be printed for future use. The designer can cause the coordinates of a point to be displayed simply by pointing the lightpen and pressing a button. The displayed coordinates are in inches, full scale with respect to a meaningful reference point rather than in arbitrary units which would have to be scaled or converted in order to be understood.

Frequently, the area available for the workplace is predetermined or at least constrained by some maximum dimensions. The size and location of some control panels may also be known. If workplace constraints are known in advance, they may be entered from one or any combination of these input devices:

a) Lightpen (on CRT)
b) Keyboard (on CRT)
c) Punched cards
d) Magnetic tape storage
e) Disc storage

The user can temporarily prevent certain characteristics of the workplace from being displayed, without removing them from the workplace storage arrays. To eliminate the projection of a particular control panel, the user simply points the lightpen at the panel and presses a button. This technique allows the operator to unclutter a very complex workplace. After the workplace has been designed around the man-model, the designer may evaluate the workplace by the following method.

A major feature of the COMBIMAN is its utility in evaluating workplaces. These generally fall into three categories:

a) Existing workplaces.
b) Conceptual workplaces (which have not been constructed, but exist as an engineering drawing).
c) Workplaces generated with the lightpen in on-line design operations.

Once a workplace has been entered into the program, it exists in three dimensions and can be made to interact with the man-model. Although the CRT is a two-dimensional display, two orthogonal views are simultaneously projected and can be rotated for viewing at any angle. If the user wants to take a closer look at some feature of the display, that feature can be magnified to the desired sizes. Regardless of the scale of the display, all coordinates and dimensions are stored in full scale.

Presently, the operator has several options in defining the body segment dimensions for the man-model:

a) Direct Measure: Specific individuals are entered into the model from the keyboard or punched cards. Although this method is rarely used in designing workplaces, it is very useful for the validation of the model, which is in progress.
b) Stored Individual Data: Data from anthropometric surveys are stored on computer tapes. Dimensions of a selected individual can be recalled and used to dimension the man-model.

c) Data Base Summary Statistics: Percentiles computed from large samples are used to define the man-model. Because a 5th percentile man is not an assemblage of 5th percentile body segments, the user must select a separate percentile value for each of the critical variables by selecting the desired value from a list of displayed percentile values. The lightpen is used to check off the desired percentile value as each critical dimension is successively underlined.

d) Computer-Aided Dimensioning: Assists the user in generating abstract, but realistic man-models from anthropometric survey data.

This last method is most useful for workplace evaluation. The user starts by defining the body characteristic most relevant to the evaluation. This characteristic may be a dimension (such as sitting height, arm length, etc.) or a mass (such as total body mass or some segment mass) and can be defined either as an actual measure or a percentile value. Of all the methods for dimensioning a man-model for workplace evaluation, this one is the most useful. It is both fast and accurate. It allows the user to call up a wide range of man-models with critical dimensions determined by the nature of the task.

COMBIMAN can define a complex range of head and eye positions with great accuracy. Because of this capability, the incorporation of visibility plots into the COMBIMAN programs was a logical development. In addition, because of the ease and accuracy with which the program handles three-dimensional geometry, the COMBIMAN visibility plots contain additional information which increases the utility of the output, specifically, the three-dimensional coordinates of

the workplace with respect to the viewing angle. Using the cockpit as an example, the visibility plot program scans the frame of the canopy and plots the vertical viewing angle for each integer degree within the horizontal field-of-view. The printout shows the three-dimensional coordinates of the canopy frame at each five-degree increment of the horizontal angle. These coordinates are given in the aircraft coordinate system, so that any point in question may be precisely located on the cockpit drawing. Such a correlation between look-angle and workplace coordinates makes this type of visibility plot extremely useful to the design engineer since it provides accurate feedback of the effect of hardware modifications on the external visibility of the pilot. When evaluating the external visibility characteristics of a certain cockpit, the designer can easily vary any of the following:

a) Size of the operator (such as sitting eye height based on relevant anthropometric surveys).
b) Seat adjustment (vertically, horizontally, or both).
c) Head position (which may be a complex function of upper body position).
d) Visual restrictions (helmet, helmet-mounted displays, etc.).

3.9.5.12 Computer Accommodated Percentage Evaluation (CAPE)

Aircraft cockpits and many other workspaces traditionally have been designed without knowledge of the proportion of the user population that is accommodated with safety and full capability. In aircraft cockpit design, for example, designers have been directed to develop cockpits that accommodated 5th through 95th percentile operators. However, crew system designers are designing for the 5th through 95th percentile population only one dimension at a time.

The combination of all the necessary dimensions that make up a workspace design, limits the operators to a much smaller actual range than 5th through 95th percentile. It has been shown that more than 52 percent of the 1964 population of naval aviators would be excluded when 5th and 95th percentile critical limits are imposed. This led to the development of CAPE which is a Monte Carlo model for generating representative pilot anthropometric features, a link-man model, and an adjustable workspace model so that the workspace accommodated percentage could be estimated and maximized (Ref. 48, Bittner, 1975).

The computerized accommodated percentage evaluation (CAPE) model has two options: exclusion demonstration and cockpit analysis. Each option, and its underlying model with components, is described in summary form below. More detailed descriptions of model options, their components and the total CAPE model are contained in Reference 48.

An exclusion demonstration determines what percentage of a potential population is excluded from a workspace design with respect to each anthropometric feature entered into the program. This CAPE option may be considered to be composed of two components, an exclusion limits component and a Monte Carlo sample generator.

The Exclusion Limits provides for the entry, storage, and utilization of user-provided standard score limits of anthropometric variables required for exclusion studies. For each variable involved in an exclusion demonstration analysis, high cutoff and low cutoff values must be input by the user. This component of the analysis provides for the

sequential testing, element by element, of Monte Carlo-generated standard score vectors to determine if the vectors are within the limits set by the high and low standard score boundaries (populations of standard scores have means of zero and standard deviations of one.) Rejection of any component test is defined as nonaccommodation of that (sample subject) feature vector.

The Monte Carlo Sample Generator Component generates quasi-random vectors of standard scores that match a user-provided correlation or correlation square-root matrix. It is based on a method, which generates standard score feature vectors with a given correlation matrix. Conformable vectors of quasi-random normal variants generated by a subroutine are premultiplied by the square-root of the desired correlation matrix to produce a quasi-random score vector. This vector can be viewed as a sample subject feature vector whose elements have been converted into standard scores.

The cockpit analysis determines the percentage of a population that will be excluded from a cockpit design based on the geometric parameters of the workspace. The cockpit analysis option of the CAPE program can be thought of as being composed of four components: a) a pilot link system component, b) a sample pilot generator component, c) a component characterizing a seat-cockpit layout, and d) a cockpit testing component.

3.9.6 Test and Evaluation

In order to verify the man-machine aspects of system design and to gather data for use in design of later systems, a concerted HE T&E effort must be accomplished. During this period of system development, the human engineer has several important responsibilities:

a) Assurance that applicable HE T&E requirements are accomplished;
b) Demonstrate conformance of system, equipment and facility design criteria;
c) Confirm compliance with performance requirements where the operator or maintainer is a significant part of such system performance;
d) Obtain quantitative measures of system performance which are a function of man-machine interaction; and
e) Determine if undesirable design or procedural aspects have been introduced.

Many of the most popular T&E techniques which are appropriate for use of HE are presented in the following sections. Depending on the nature of the program, only a few of these techniques would normally be used. Sufficient time or HE evaluator effort does not exist to use anywhere near all of the techniques for a single program. Table 3.9-8 is provided to compare the T&E techniques on the basis of their time to perform, complexity, cost, and cost effectiveness. References 49 (Meister, 1965) and 50 (Potempa, 1968) provide additional information on many of the HE T&E techniques included herein. References 50 and 51 (Geer, 1977) also provide data on additional HE T&E techniques not included herein.

3.9.6.1 Direct Continuous Observation

Description: This technique is simply the process of taking a relatively continuous record of the task or work activity or some aspect of the test performance. The operation may consist of an observer keeping a running log or description of the test activity as he understands it. The data may be recorded by hand or on a clip board, or some of the more sophisticated

Table 3.9-8. Test and Evaluation Techniques Selection Chart

Alternative techniques	Selection evaluation characteristics: Most applicable program phase				Relative complexity			Relative time to perform			Relative cost (man-years)			Relative cost effectiveness		
	Conceptual	Validation	FSD	Prod/deployment	Simple	Average	Complex	Short	Medium	Long	Low	Medium	High	Low	Medium	High
1 Direct continuous observation		X	X		X				X			X			X	
2 Direct sampled observation		X	X		X			X			X				X	
3 Specification compli. summary sheet		X	X		X				X			X			X	
4 Technical order functional evaluation			X	X	X				X			X			X	
5 HFTEMAN		X	X	X		X			X	X		X			X	X
6 Environment and Performance Measurement equipment		X	X	X		X		X	X			X			X	
7 Systems records review		X	X	X	X				X	X		X			X	
8 Test participant history record		X	X	X	X			X			X				X	
9 Interviews	X	X	X	X		X			X			X			X	
10 Questionnaires	X	X	X	X		X			X			X			X	
11 Motion pictures		X	X			X			X				X	X	X	
12 Sound tapes		X	X		X			X			X			X	X	
13 Video tapes		X	X			X			X				X	X	X	
14 Photography		X	X	X	X			X			X				X	
15 Event recording		X	X		X	X		X	X		X	X			X	
16 Secondary task monitoring			X				X		X	X			X	X		
17 Physiological instrumentation			X				X		X	X			X	X	X	
18 Physical measurement		X	X			X			X			X			X	
19 Online interactive simulation		X	X				X			X			X	X	X	
20 Statistical analysis		X	X			X	X		X	X		X			X	

techniques/tools may be used for recording events and times. Automatic recording techniques such as photographs, movies, and sound and video tapes may also be used along with direct observation.

Procedure: The detail of the observed data is in accordance with the basic considerations indicated in Section 3.9. The observer should be skilled at being able to discriminate what significant events occur during the test. These events should be summarized and interpreted for later action. The observer must be familiar with the anticipated man-machine system performance. He will observe test participants while they are using either mockups or actual hardware. The observer should be particularly interested in obtaining data on operator task times and errors. Data as to the observer's estimates of participants' training, skills and quantities should also be recorded. Life support, safety and hardware design criteria may also be observed.

The use of the direct observation technique involves the use of mockups or hardware. Therefore, the most appropriate time to use this technique would be any time after the system concept has evolved sufficiently to produce three-dimensional mockups.

Use/Validity: Observation is one of the most common methods of evaluating personnel and system performance. It is used to some extent in some form in every test and evaluation. Despite the increasing use of automatic recording devices, the requirement for direct observation will never be completely eliminated.

Observation may be used on any portion of a total system, a subsystem, or on system components. It is useful for T&E of single task performance or the simultaneous operation of several tasks by several test participants. It is simple to perform in comparison with other T&E techniques.

During the conduct of the test, it is possible for the observer to do more than simply record test occurrences. The observer may evaluate test data for possible recommendations or test action items. If direct continuous observation is not used, there is a risk of missing an overall impression of the test as well as random test events or details that would otherwise be overlooked.

One of the disadvantages of using this technique is the requirement for specialized observers for each of the different test aspects or categories. It is seldom possible for a single observer to learn a sufficient amount about all system aspects to perform an adequate job of observing all system tests. The use of continuous observation implies some periods of test observation that are not productive in terms of gathering HE T&E data.

3.9.6.2 Direct Sampled Observation

Description: This technique is identical to the previously listed one with the exception of the amount of time spent by the observer observing the test. The particular times chosen to perform test observation should, of course, be those which coincide with the performance of critical tasks. The determination of anticipated critical tasks should be made on the basis of the program's preceding systems analysis effort. Random sampling for T&E data may be performed if possible critical tasks have not been predicted by analysis.

Use/Validity: The only difference in the use or validity of the sampled observation technique as compared to continuous observation is in cost savings and the risk of missing significant T&E data. It stands to reason that if the tests are not observed continuously, the test observers may be used to perform other HFE T&E tasks on other tests or in data reduction and evaluation of previously conducted tests. The number of personnel required to perform HFE T&E may be cut by a factor of one half or more. The disadvantage of the sampling technique is in running the risk of missing important operator performance data or other important HFE related data. If critical tasks cannot be predetermined, test sampling should be performed with relative frequency. All basic categories or types of operator/equipment tasks should be observed several times in order to prevent skewed data.

3.9.6.3 Specification Compliance Summary Sheet

Description: This is a form that is used to verify that system performance is in accordance with specified HFE requirements. Briefly, the total process of verifying HFE specification compliance is: first to decide the best method to verify the specification requirement (i.e., analysis, demonstration, or quantitative data), second to perform the analysis/test and third to document the results. In any case, reports are written as to the analysis or test results. The Specification Compliance Summary Sheet is a way of summarizing this compliance or lack of compliance.

Procedure: The evaluator needs first to have a thorough knowledge of all HFE aspects of the contract statement of work and the accompanying system specifications. In particular, he should understand the specification Section 4.0 requirements (quality assurance/testing).

After the test, demonstration, or analysis has been performed and reported, the summary sheet form is completed. The form contains a space to indicate the specification number and complete section being verified. Space is provided for a summary of the test/analysis results. Signature blocks are provided for persons preparing the summary sheets and approving the verification of specification performance.

Use/Validity: This technique is used by only a few HFE T&E organizations. However, this lack of use is not an indication of the need for this type of evaluation. The contract and related system specifications are by far the most important program requirements. This technique is unique in that it zeroes in on these important requirements, rather than concerning itself with T&E of indirect system requirements.

The Specification Compliance Summary Sheet is an excellent way to verify the Section 4.0 specification requirements. The only disadvantage associated with the use of this form is in the large amount of time required to fill it out. The effort preceding the use of this form may be considerable but that effort is a part of the already existing HFE T&E program. If this technique is not used, there is a risk that some important aspect of HFE design criteria may be overlooked both by designers and by test observers.

3.9.6.4 Technical Order Functional Evaluation

Description: As its title would indicate, this technique is designed to evaluate technical orders or publications pertaining to the test. The technique is based on the use of a form to be

completed by the test observers while they are performing their other direct observations of the test. The technical publications must be evaluated as to their usefulness and adequacy in three areas:

a) Job Instructions

b) Training

c) Job Performance Aids

Job Instructions tell how to accomplish a task by providing the step-by-step procedures along with the necessary illustrative drawings. Most technical publications which require validation or verification provide support for training. There are three major types of job performance aids which are identified as follows:

a) Job Guides (including inspection guideline manuals). These guides contain instructions for fixed-procedure tasks such as checkout, adjustment, removal, and replacement.

b) Fully Proceduralized Trouble Shooting Aids spell out the steps to follow in isolating malfunctions to a replaceable or repairable unit. The steps start with observable symptoms of malfunction.

c) Troubleshooting Decision Aids provide diagrammatic and supporting textual information which will help the technician decide what steps to take in isolating malfunctions to a replaceable or repairable unit.

The following sample evaluation form (Figure 3.9-25) is structured so that the first three questions require two judgments: one dealing with the category of the section being evaluated and the other as to the adequacy. The two

E-3A

TECHNICAL ORDER FUNCTIONAL EVALUATION

ASSESS THE USABILITY OF THE IDENTIFIED PARAGRAPHS FOR INSTRUCTIONS, TRAINING, AND/OR JOB PERFORMANCE AIDS. (SEE INSTRUCTIONS ON REVERSE SIDE)

T.O. NUMBER: ____________________ TITLE: ______________________________

EVALUATOR: ______________________________ DATE: ____________________

PARAGRAPHS OR SECTIONS EVALUATED: (GIVE NUMBER AND SUBJECT)

NOTE: PARAGRAPHS OR SECTIONS COVERED SHOULD BE CONSECUTIVE AND GROUPED SO THAT ANSWERS GIVEN APPLY TO ALL PARAGRAPHS LISTED.

T.O. VERIFICATION PERSONNEL REQUIREMENTS

NAME	AFSC	NAME	AFSC

CONDITIONS AT VERIFICATION: (INCLUDE EQUIPMENT INVOLVED, WHERE PERFORMED, ETC.)

EVALUATION: (USE ADDITIONAL SHEETS FOR COMMENTS)

1. DO THE PARAGRAPHS CONSITUTE JOB INSTRUCTIONS? YES___ NO___
   IF YES, ARE THEY ADEQUATE? YES___ NO___
2. SHOULD THE PARAGRAPHS BE USED FOR TRAINING? YES___ NO___
   IF YES, ARE THEY ADEQUATE? YES___ NO___
3. DO THEY CONSITUTE JOB PERFORMANCE AIDS? YES___ NO___
   IF YES, ARE THEY ADEQUATE? YES___ NO___
4. ARE THE STEPS IN LOGICAL SEQUENCE AND DO THE ELIMINATE BACK TRACKING WHERE POSSIBLE? YES___ NO___
5. DID THE INDIVIDUALS DEMONSTRATING THE OPERATION EXPERIENCE ANY DIFFICULTY AS EVIDENCED BY ERRORS, TOO MUCH TIME, OR NEED FOR ASSISTANCE? YES___ NO___
6. ARE THE FUNCTIONS DESCRIBED SUFFICIENTLY NEW OR COMPLEX AS TO REQUIRE TRAINING? YES___ NO___
7. IS IT NECESSARY TO PROVIDE ADDITIONAL BACKGROUND OR SUPPLEMENTARY INFORMATION IN ORDER FOR THE USER TO UNDERSTAND WHAT?, HOW?, WHEN?, WHERE?, ETC.? YES___ NO___

Figure 3.9-25: Sample Technical Order Functional Evaluation Form

questions are to be answered by the test evaluator/observer, as well as the test participants. The remaining questions (4 through 7) deal with the qualitative characteristics of the T.O.

Procedure: Most sections of the form are self-explanatory, however, the following sections should be completed as indicated:

Evaluator: Identify individual(s) interviewed or those contributing to the evaluation.

Paragraphs Evaluated: List only those paragraphs for which the evaluation applies. In some cases, this can be done in large blocks. There will be some events where several separate forms will have to be completed.

T. O. Verification Personnel Requirements: When verification is performed, the names and rate (rank) as well as skill code of the participants is required.

Prior to conducting this type of evaluation, the observer or evaluator must have a knowledge of the technical manual he is to evaluate. He must also be familiar with estimated system and operator/maintainer performance. The total technical order functional evaluation process will result in either verification of the technical data or revisions or recommendations for new technical data. These revisions will be coordinated with the publications writers.

Use/Validity: Depending on the scope or charter of the HFE T&E effort, technical order evaluation may or may not be performed. If it is performed (by HE personnel), it may be accomplished at any time with the evaluation of any evolving systems (as opposed to future or existing systems). The effort required

to perform this evaluation is relatively low and it is therefore recommended as a task to be accomplished by HFE or other personnel. Failure to perform this evaluation can result in several maintenance and operational mistakes that would otherwise have been avoided. The cost to perform the evaluation must be considered to be relatively low, particularly compared to the potential cost of the mistakes.

3.9.6.5 Human Factors Test and Evaluation Manual (HFTEMAN)

Description: HFTEMAN must be considered as considerably more than an HE T&E technique. It is designed to assist the HF engineer in the areas of test plan preparation, test conduct, test data evaluation and analysis, and test report preparation. The HFTEMAN consists of two documents: the first contains detailed HFE test data and the second is a guide book supplement that contains specific HFE design criteria (Ref. 52, Navy, 1976).

Procedure: The procedure of using HFTEMAN may be considered as a five step process. This procedure is well detailed on the first few pages of the manual. The first step requires that test items be classified as to vehicles, weapons, electronics, etc. The second step is to identify both the user functions and tasks related to this type of equipment; in other words, a selection is made of what to evaluate and the criteria to be used in the evaluation tests. The third step decides what human factor considerations and what item components are relevant. The test observer should review the task list and test item design description to identify which of the test item components presented in the matrix apply to the item under test, and which human factors considerations are important. In the fourth step, the test evaluator goes from the cells of HF considerations/task item components to cells containing the exact test criteria as indicated on a separate

(opposite) page. The last step is to prepare the HFE test plan which includes an "objective" (taken from HFTEMAN), "criteria" (taken from HFTEMAN), and "methodology" (taken from the HFTEMAN Supplement). The "data required" also are provided in both the HFTEMAN and HFTEMAN Supplement.

It is recommended that the test observer be thoroughly familiar with the HFTEMAN contents before he starts this procedure. The end products of this effort should be both an itemized listing of all HFE system deficient items and a general feeling of pilot or other operator acceptance of the hardware item.

Use/Validity: HFTEMAN may be used on any program at any time during the program evolution. HFTEMAN is of more than normal value in that it provides both the basis on which to build an HE checklist (Ref. Section 3.9.5) and all of the rest of the necessary HFE T&E planning and conduct.

HFTEMAN has broad applicability. No special test equipment is required to use with this technique and it will be of use with any military system. If HFTEMAN is not used, the appropriate HE test planning must be based on other less coordinated resources.

HFTEMAN has derived from the U.S. Army TECOM Human Factors Engineering Data Guide for Evaluation (HEDGE). The Army guide has been used successfully since its pubication in 1974. Reference 53 (Army, 1074) contains additional information on HEDGE.

3.9.6.6 Environment and Performance Measuring Equipment

There are several different items of test or measuring equipment that are extremely useful to the HE test observer. A few of these T&E tools are presented in separate sections, but most are included here. The following subparagraphs indicate the item of HE test equipment along with a brief description of its use:

a) Photometer. Measures ambient illumination over a range of levels from approximately .005 to 25,000 foot candles. This is an extremely useful tool. It is particularly valuable for verifying specification compliance with light level requirements. Sophisticated mockups or prototype equipment/facilities are required for the proper use. Most photometers are relatively easy to use.

b) Spot Brightness Meter. Measures small area brightnesses in foot-lamberts within angles of approximately one degree or less. This tool is most useful for measuring prototype hardware display brightness such as from LED's or CRT's. Specification compliance may be verified with the spot brightness meter.

c) Sound Level Meter and Analyzer. Measures steady state sound in the approximate range from 10 to 150 dB for standard weighted noise curves. The analyzer provides active band analysis for the more critical speech range center frequencies. Specification compliance in terms of noise curves and speech interference levels may be verified with this equipment. Hazards to test personnel may be checked prior to overexposure conditions. Most sound level meters are relatively easy to use.

d) Vibration Meter and Analyzer. Measures amplitude and frequency components of complex vibrations. The analyzer may be used to determine amplitudes at selectable frequency bands in a range from 2.5 Hz to 25 KHz. Potential vibration hazards to test participants may be checked before actual test exposure. Specification compliance may also be verified.

e) Thermometer. Measures air, surface, or liquid temperatures. May provide a digital readout in either Celsius (centegrade) or Fahrenheit. Should include capability for attachment to several temperature sensor probes.

f) Anemometer. Measures local air flow in the range of 0 to 1000 ft/minute. This device is most useful for determining crew comfort conditions.

g) Hygrometer or Psychrometer. Measures relative humidity using the wet and dry bulb thermometer method. This device is also very useful for determining conditions for crew comfort.

h) Gas Tester. Permits convenient short-term sampling and evaluation of many toxic gases, vapors and fumes.

i) Force, Torque and Dimension Kit. Various instruments for measurement of a wide variety of operator or equipment forces, torques and distances. The force measurement limits should be from 1/4 oz. to 250 lbs. Torque measurement should range from 1/2 in. - lb. to 160 fr. - lbs. A tape measure should be capable of measuring distances up to 50 feet. Scales should also be for measuring centimeters, millimeters, inches and fractions of inches. A protractor is useful for angular measurement.

j) <u>Anthropometry Instrument Kit</u>. Allows measurement of significant body dimensions using the anthropometer, spreading calipers, sliding caliper, gonimeter and tape measure. The measurement of test participants is critical to the evaluation of workspace layouts, particularly when egress and ingress are important considerations. Care should be taken to insure the proper measurement procedures are adhered to while obtaining participant anthropometric data.

3.9.6.7 System Records Review

Description: There are a number of typical test and evaluation program records that may be useful for review by the HE personnel. This technique, the review of system T&E records, is unique in that there is no direct contact between the test evaluator and the test participants. All that is required on the part of HFE evaluators is to obtain permission to review the existing test records and to go ahead with the tedious task of looking through them. The evaluator should, of course, have some sort of system knowledge to know what he is looking for in terms of anticipated human performance. Typically, system records will contain test logs, maintenance records, and debriefing records.

The HE evaluator may find data on equipment operation problems, technical publication inadequacies, human initiated errors, and training inadequancies.

Use/Validity: This technique is best used for gathering man-machine performance data. Because the HE evaluator does not actually observe the test, it is doubtful that sufficient evaluation can reliably take place just by reading a word description of what occurred. Human performance tests may have to be scheduled for the purpose of formal observation of HE personnel.

The problem with a review of test records is that they tend not to be designed for gathering human factors data. What the evaluator is able to obtain from these records may be misleading. There is significant risk that HE problems that could be readily apparent by direct observation, are unobserved or obscured by other less significant test data. In order to enhance the value of system records review, the personnel who initiate these records should be indoctrinated in the value of HE and HE T&E.

It is generally agreed that the use of this technique is not required. It is recommended that it be performed only when direct HE observation is not possible. The debriefing records should be the most useful of all the system records normally available.

3.9.6.8 Test Participant History Record

Description: This is not a direct test technique but rather a method of improving the test evaluation process. The Test Participant History Record form is used to collect data on personnel participation in the tests, if possible. Otherwise, the form may be completed as part of the post-test interview. The sample form included in the following pages (Figure 3.9-26) emphasizes participant training, experience in systems similar to the one being tested, and participation in previous testing related to the same over all system presently being tested. This form may need to be modified to suit the needs of the particular test situation.

PS TEST PARTICIPANT HISTORY RECORD

NAME/RANK ______________________________ DATE ______________

AFS/AFSC ________________________ TIME IN AFS ______________

TRAINING

COURSE	DATE	PARTICIPATION IN PREVIOUS TESTING

RELATED EXPERIENCE

Figure 3.9-26: Sample Test Participant History Record

Use/Validity: The purpose or use of this form is to assist in the evaluation of the obtained test data. For example, if the test participant has had little or no experience in performing tasks similar to the ones he has been given to do as a test participant, and he does very well, then the conclusion is that the man-machine interface being tested has been well designed and developed. If, on the other hand, his performance is poor, the problem may or may not be due to poor man-machine interface design. A more experienced test participant will have to be given the same tasks to perform. The time and effort it takes to complete the form is small, and the potential value of having the test participant's significant history is large.

3.9.6.9 Interviews

Description: The HE T&E interview technique is simply the process of the HE test evaluator discussing the test events with the test participants. This discussion should be structured in order to insure that the most information is obtained in the least amount of time.

Specific variations to the general interview technique may be of use for particular situations. For example, considerable test and evaluation data may be obtained from training instructors. They are particularly knowledgeable in regard to student problems with new systems because of inadequacies in the system design.

Procedure: The first step in the process of conducting the interview is to develop a format for asking questions of the participants (interviewees). The format may be structured like a checklist to insure that all pertinent aspects of the test are considered. The second step is to select an interviewer

who has had experience with the system being evaluated. It is important that he has observed the actual test conducted. The next step is to arrange a time to conduct the interview with the test participant.

The interviewee should be questioned about the task he has performed. He should describe what he thinks his test task consists of in terms of his duties and those of others. His opinions should be obtained on the adequacy of the equipment, technical data, logistics and preparatory training.

The interview should be conducted as soon as practical after the actual test, hopefully within a few hours. If possible, the interview should be conducted on a one to one basis rather than one interviewer questioning several participants at one time. The area selected for the interview should be relatively quiet with a minimum of distractions. The time taken to conduct the interview should be less than half an hour. Interviews which are longer than this start to get boring and become an imposition on the interviewee.

The HE interviewer must take care to insure that he is obtaining the interviewees actual opinions as to the test situations and not what the interviewee thinks the interviewer wants to hear. The participant must be assured that he is not being graded in any way on his responses. The HE interviewer should try to quickly develop a rapport with participants. If the participant agrees, a tape recording may be taken of the interview. However, whether the participant agrees or not, some individuals tend to be intimidated by the use of tape recordings and caution must be used in this regard.

Another example of an interview technique is the "critical incident technique". The critical incident technique consists of a set of procedures for collecting observations of human behavior in such a way as to facilitate their potential usefulness in solving practical problems. A critical incident is any observable human activity, the purpose and serious effects of which seems clear to the observer. The five step procedure is basically as follows: a) Determination of the general purpose of the activity; b) Development of plans for collecting incidents regarding the activity and instructions to the persons who are to report their observations; c) Collection of relative objective data; d) Analysis of the data; and e) Interpretation and reporting of the statement of the requirements of the activity. The gathering of the series of incidents consists of inquiry as to most effective or ineffective behavior (or critical incident) of specified activities/jobs. Although the incidents may be secured by interviews, they may also be obtained by written responses.

The end product of the interview is a quantity of test data (facts and opinions) to review and evaluate for the purpose of presenting system problems and recommendations, and in many cases system verification.

Use/Validity: The interview is one of the most significant evaluation methods used. It is a simple, low cost, quickly used technique. Every test involves a certain amount of test data that cannot be obtained through normal observation. Interviews with the test participants draw directly on this type of data and on the knowledge of the presently available system experts. Interviews do not require the use of test facilities. They may be conducted in an area remote from the test site.

The purpose of an interview is to find out either objective facts related to the system about which the interviewee has some knowledge, or objective facts, attitudes, or opinions about how he feels about some test aspect. The interview must be designed to obtain these facts with as much clarity and accuracy as possible.

The interview attains its greatest value from the relationship which is established between the interviewer and the respondent. In a properly conducted interview, where a genuine rapport is established between the interviewer and the interviewee, it is possible to obtain more detailed and reliable data than from the self-administered questionnaire.

One caution that must be pointed out in the use of interviews is bias on the part of the interviewer or interviewee. Ideally, the interview results in the interviewee supplying accurate information to the interviewer. However, the influence of bias can alter the results to such an extent that the answers are of little or no value in the final analysis. The interviewer may bias the interview by tone of voice, the way in which the questions are phrased, or even by facial expressions. These and other sources of bias can be greatly reduced through recognition of the problem and by training and experience.

Another caution associated with the use of interviews is that they cannot be used as a substitute for direct test observation. They should be used as one of several HE test and evaluation techniques. Additional data on interview techniques is provided in Reference 54 (Army, 1975).

3.9.6.10 Questionnaires

Description: The basic tool for obtaining subjective data is the questionnaire. It is the most frequently used and most difficult to construct of the subjective techniques. The questionnaire provides a structured method for asking a series of predetermined questions in order to obtain measurable expressions of attitudes, preferences and opinions. The design of a questionnaire which will produce valid and reliable results requires a measure of skill and experience. Unfortunately, questionnaire design and construction cannot be taught from books; the requirements for each test are somewhat different and present new and different problems. However, there are certain rules and principles of questionnaire design and administration which, when followed, eliminate some of the more common pitfalls which result in faulty questions and invalid results. The following material, especially the references, are intended to provide quidance for planning, designing and administering the questionnaire.

Procedure: The method of questionnaire design applicable to the types of tests conducted by HE T&E personnel may be divided into seven logical steps:

a) Preliminary planning.

b) Selection of the question form.

c) Wording of the questions.

d) Formulating the questionnaire.

e) Pretesting.

f) Administering the questionnaire.

g) Quantification and analysis of questionnaire data.

The preparation of a questionnaire requires great care and a background knowledge of the system to be tested. Knowledge also is required regarding the background of personnel to whom the questionnaire will be administered, and the type of analysis which ill be made of the results. Too often a questionnaire is prepared with insufficient planning. The problems involved and the weaknesses in the design are frequently not recognized until such time as the results are interpreted.

There are four basic question forms that may be used in a questionnaire:

a) The open-end or free-answer.

b) The dichotomous or two-way.

c) The multiple choice.

d) The rating scale.

Each form has its merits and disadvantages of which the questionnaire designer must be aware and must weigh carefully before final selection. No one question form is superior to the others in all cases. In order to select one form over another, the designer must be aware of the advantages and disadvantages of each and choose that form which best meets the needs of the particular test situation.

The most important, and also the most difficult, aspect of questionnaire construction is the wording of the questions. Most authorities agree that faulty or improper wording of questions accounts for the greatest source of error in the questionnaire technique. Errors and distortions in the final

data are often caused by misunderstanding and misinterpretation of questions due to use of an improper vocabulary level and ambiguous phrasing. In addition to selecting the question forms and wording the questions, it also is necessary to consider such factors as the sequence of the questions and the format for presentation and data collection. A check must be made of all questions to insure complete and accurate coverage of all data required by the test objectives and test critical issues.

A questionnaire is subject to many variables and must not be assumed to be perfected until it has been subjected to trial use. The pretest provides an opportunity to try the questionnaire out on a small sample of respondents. The results of this trial may then be used to make revisions and improvements as necessary before test administration. The pretest is the final and validating step in the method of questionnaire construction.

The product obtained from administration of the questionnaire consists of subjective words or phrases. This information may be quantified and converted to figures or numbers that can be tabulated and analyzed. The end product of the questionnaire may be a simple frequency distribution of responses to each question summarized in terms of numbers, proportions or percentages. The data may be further summarized to include averages, standard deviations, or correlations. The summaries also may include statistical analyses showing the statistical significance of differences or correlations obtained. These quantified data must then be tabulated and analyzed. The results usually are summarized in tabular form for inclusion in a final report.

When compared to the interview, there are several similarities and differences with the questionnaire. Both the questionnaire and interview should be conducted within a few hours of the test for best results. Both techniques may be conducted away from the test area. Although the questionnaire must be more structured than the interview, the questionnaire may still include open-ended questions. The differences are in that HFE personnel need not be present while the questionnaire is being filled out. The questionnaire is inherently easier to use in evaluation or analysis of the participant responses.

Use/Validity: The questionnaire is a subjective measurement tool for systematically obtaining attitudinal responses from a selected group of individuals. The function of the questionnaire is to communicate information. When properly formatted, it also aids in the tabulation of data and analysis of results. The questionnaire is used to assess a wide variety of qualitative variables such as acceptance, ease of use and preference. It may be administered to small groups of technical personnel, such as those involved in highly controlled engineering tests, or to larger representative cross-sections of service personnel.

Knowledge of individual or group attitudes provides valuable information regarding reactions, feelings, and preferences toward military systems. Since attitudes determine behavior, questionnaire responses of a representative sample o. the population permit a reliable estimate of group reactions to systems in actual use. These results also may be used to anticipate and thereby avoid future developmental problems.

The questionnaire is appropriate for use in all types of tests. It should be used to obtain subjective data when objective measurement is not feasible and when qualitative data are needed to supplement objective measurements. However, it should not be used in place of direct observation techniques if observation is possible.

A disadvantage of the questionnaire is that test participants won't respond in writing to the degree that they would in talking in a response to an interview. The effort to write responses to open-ended questions is greater than the effort to talk. Another disadvantage of the questionnaire, compared to the interview, is the inability of the HE observer to pursue a participant response that is unexpected but potentially fruitful.

One of the most difficult problems to overcome in questionnaire design is the misunderstanding on the part of individuals as to what a questionnaire is and how it should be used. There are those who believe that anyone who can write well and use a little common sense can construct a good questionnaire. The seriousness of this faulty assumption is illustrated by the fact that an improperly designed and poorly worded questionnaire will still yield data in the form of numbers, frequencies and percentages. These numbers are amenable to statistical analysis and may even produce statistically significant findings. The real tragedy is that these erroneous findings may be used to draw false conclusions which, in turn, contribute to faulty critical decisions regarding the utility of an item. References 54 (Army, 1975) and 65 (Army 1976, 1979) provide additional information on the use of questionnaires.

3.9.6.11 Motion Pictures

Description: This technique is similar to the use of video tapes (see Paragraph 3.9.6.13). It is the process of filming participant performance as a part of a system test.

As with video tapes, actual prototype hardware or sophisticated mockups should be available to justify the use of this technique. Less sophisticated mockups imply more uncertainty in design, and therefore a greater risk in expending a motion picture effort on unsuccessful concepts.

Trained test participants must be available for observation of their appropriate tasks. The cameraman, and particularly the HFE observer, should be familiar with the test operation being performed. The knowledge of when to take close-in footage of a particular critical task is important. As in the case with video cameras, a dry run is recommended to insure the filming is properly performed. Consultation with all personnel familiar with the anticipated test events is advised.

The following equipment is necessary to implement this technique:

a) camera and (film)
b) lens
c) lights
d) projector
e) screen

A tripod may be required, depending on the test situation.

Permission to use cameras in secure areas must be obtained and the camera equipment and cameraman properly scheduled.

Use/Validity: This technique was comparatively more useful before the development of video tapes. Video tapes are now becoming more popular for that type of test and evaluation process.

However, when compared to all other techniques, motion pictures still offer the advantages of: permanent precise records of observed events, repeated observations of the same event, slow and fast motion study of real-time events, use in hazardous areas, and record of task activities as well as the related background situation. The data gathered may be presented to large groups of people.

The disadvantages are in the cost and effort to provide the proper equipment, particularly for processing and viewing the film. Skilled technicians are generally required for the filming of motion pictures.

Motion pictures are not as useful as video tapes in that they must be processed to be viewed. Instant playback of a film cannot be made to insure the adequacy of that particular test record. After the processing, a projector and screen are required. The film cannot be reused as video tape can. However, the cost of the least expensive movie equipment is less than the least expensive video equipment. The process of recording and presenting observed test tasks in slow motion or fast-action is cheaper with motion pictures. Reference 55 (Adams, 1962) provides more information on the use of motion pictures for HE evaluation.

3.9.6.12 Sound Tapes

Description: The use of this technique is now so common that a description is somewhat superfluous. Tape recorders are now both inexpensive and portable. They are used extensively for tasks other than formal test observation. Their use in HE T&E is somewhat like that of video tapes but without the restrictions of size, security, transportation and cost.

Test observers commonly use sound tape recorders to maintain a complete record of test conversation and events. Test notes may be verbally entered by the observers themselves. The recorders may also be used to record participant interview comments. The recorder may be linked into the intercommunication system if such is used as a part of a large scale multioperator test. The use of both sound tapes and video tapes together is frequently valuable.

Use/Validity: Sound tapes are now a well used test/evaluation technique. Their use is extremely easy and inexpensive. They have the same advantages as the video tapes in that they are a permanent record of events (audio), they may be repeatedly reviewed, they may be used with time tags if desired. In addition to this, sound tape recordings negate the need for detailed handwritten notes.

One disadvantage to the use of the recordings is in the quality of the reproduction if a high ambient noise is present near the test data being recorded. Another possible disadvantage is if the test participant becomes self-conscious due to the use of the recorder. This would be more noticeable during an interview.

If the tape recorders are not used, good note taking becomes much more important.

3.9.6.13 Video Tapes

Description: This test and evaluation technique is the use of video cameras and related equipment to make video tape recordings for detailed review and evaluation of operator and maintenance personnel tasks.

Actual prototype hardware or extremely sophisticated mockups should be available to justify the use of this technique. Trained test participants must be available for HE evaluator observation of their appropriate tasks. The camera operator(s) and particularly the HE evaluator coordinating the data recording should be reasonably familiar with the test operation being performed. The knowledge of when to use the zoom lens to home in on a particular critical task is important. In order to be sure all the more critical tasks are properly recorded, dry (or test) runs of the test may be advisable. Consultation with all personnel familiar with the anticipated test event is recommended.

The following equipment is necessary to implement this technique:

1) video tape recorder
2) camera (preferably portable)
3) zoom lens
4) monitor
5) lights

Additional lenses, monitors and tripods may be desired depending on the complexity of the test. Sound recording equipment may also be desired. There are a number of easy-to-use video tape recording systems which might be made available to HE personnel at the test sites and at contractor facilities.

Problems associated with the use of video recordings involve: the logistics of transporting the equipment to the test site; the security of the equipment; permission to record any occurrences in secure areas (e.g., restricted flight line areas); scheduling of the video equipment and a cameraman; and request to perform recording on a possible test interference basis.

Use/Validity: There is little doubt that given the video tapes and proper display equipment, the use of this technique is of notable value. However, the cost effectiveness of the technique must be considered to be dependent upon the complexity of the task needing evaluation. Possible transportation and lighting problems should be considered also before commitment to the use of this technique.

Careful review of tape playbacks can reveal human errors and excessive task times not previously capable of being detected. The application of maintenance crew teamwork may be examined. Improper procedures may be thoroughly evaluated. Improper malfunction determinations may be traced back to the point of the original mistake. Technical publications and training can be methodically evaluated. The adequacy and proper use of tools may be verified.

Depending on how they are used, video tapes may account for less test interference than direct test observation alone. This would be true for an equal amount of test data gathered as a result of a relatively complex test. Once recorded, the data record is permanent and may be presented for use to numerous persons including contractor and customer alike. The tapes may be easily stopped, started and backtracked for repeated observation. Each task may be thoroughly examined step by step. Test sequences that may not be properly recorded may be easily reviewed and retaken.

Further advantages include the fact that observer errors are reduced, the observation can be recorded and observed remotely from what might be a hazardous or congested area. The tapes may have considerable use as training aids. They require no time to process, but motion picture films do. The tape itself is reclaimable: it may be used over and over again for different tests. The record of time tags along with the video is possible.

Disadvantages of the technique are in the requirement for special personnel or training required to use the recording equipment. The initial cost of the equipment is quite high (several thousand dollars for the recorder, camera, zoom lens, monitor, tripod and lights). Slow motion and stop action shots are possible but much more expensive. If necessary, the one alternative technique to use is motion picture film. Additional information on the use of video tapes is provided in Reference 56 (Crites, 1969).

3.9.6.14 Photography

Description: This technique is perhaps too simple to be considered as such and should be described rather as a HE test and evaluation tool. It is, very simply, the process of taking photographs of whatever tasks, objects or events that are pertinent to the HE effort. As in the case of the video records, actual prototype hardware or mockups must be available to justify the use of the tool. HE test operators must be familiar with the test to know when the critical tasks or events require the visual record.

In addition to the camera, a tripod and special lighting may be required. Flash attachments are easily used. Depending on facility and agency requirements, a photographic pass may be required. The location of the test may restrict the use of cameras. Polaroid type cameras are convenient in that they provide an instant picture for evaluation as to the need

for additional pictures. However, the quality of the instant picture cameras tends to be inferior to those which produce the large 8 x 10 shots. The results of the photography generally are appropriate for inclusion in test reports or other HE test and evaluation reporting forms.

Use/Validity: Naturally, photography is a well used HE test and evaluation tool. It is easy to use and may be done quickly. The particular advantages gained in using this technique are similar to some of those for the video tapes and motion pictures, e.g., the photograph is a permanent record which may be reviewed, it may be used as a training aid, and decreases observer errors about what really happened. Photographs are used extensively in HE testing for analysis of anthropometric interface problems.

The obvious disadvantage associated with the use of this T&E tool is in the single frame static picture rather than the dynamic picture created by motion pictures or video tapes. A small problem may be created by the logistics of obtaining the photographic equipment and/or camera personnel and the permission to use the equipment in the test area. Alternatives to photography are the more expensive video tapes or motion pictures or possibly a good fast sketcher assigned the duties of the HE test observer. In a few instances, a large number of descriptive words written in the test reports may substitute for a photograph of the situation or equipment that they are describing, but these descriptions are seldom completely satisfactory. Reference 57 (Crites, 1959) provides more information on the use of photography.

3.9.6.15 Event Recording

Description: This is a technique or method for recording test situation or event times. The equipment involved in the use of this technique varies in complexity from the stopwatch to complete systems. The more complex event recorder systems might include: an event recorder, battery pack, event control box and a signal cable. The event recorder itself should be capable of recording on several channels; the battery pack is to give portability to the operation; the control box is used to actuate the various channels in the recorder, and the signal cable is to electrically tie the control box to the recorder. Other recording systems are provided which combine these units into one easily portable package.

Procedure: The sequence of events which might occur with the use of this technique may be as follows: HE personnel who are to observe the particular test first become familiar with the planned test events. They estimate what tasks are more critical and should be recorded in terms of time performance. If the tasks to be monitored are particularly critical they may even perform a dry run of the test or plan to run multiple replications of the time critical task. The total test may be divided into several functional tasks and each such assignment allocated to a separate channel. Examples of such task functions are reading technical publications, actuating controls, reading displays and making adjustments. The channel controls are easily activated for each of the task functions as they start and stop. It may be necessary to write start labels for each event on each of the channels plotted on the recorder chart paper roll. Figure 3.9-27 shows a sample of this type of annotated record.

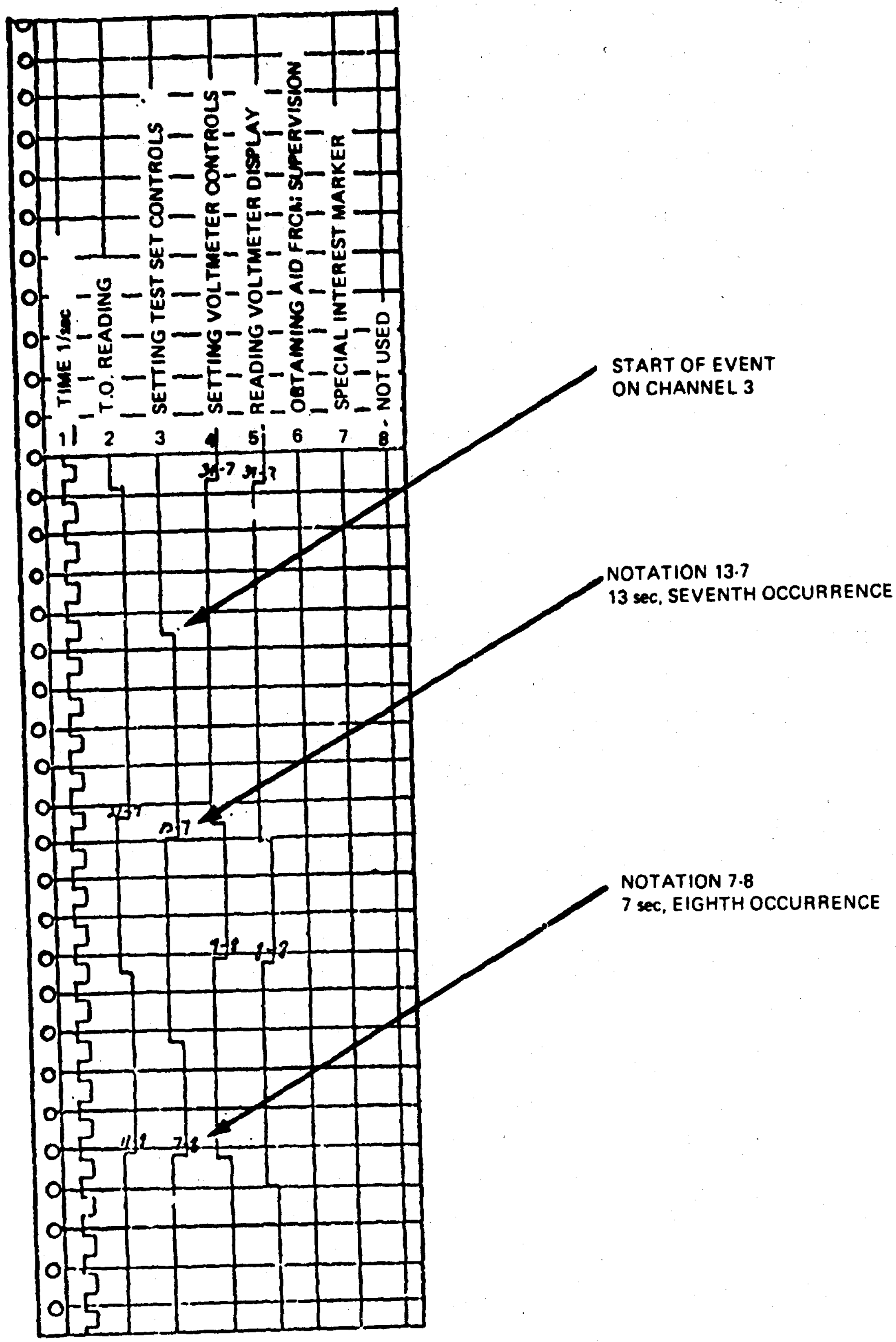


Figure 3.9-27. Sample Annotated Event Record

More recently available recording equipment does not require the use of the paper role for a record of events. The test observer simply presses combinations of keys to note task functions as they occur. Data entries record in a solid-state memory in a computer program format. The data are later transmitted to the computer by connecting the device via a simple connecting cable. In this manner, computer written reports may be written in minutes. This device includes a space for written notes on an integral note pad.

The direct outputs of each of these event recording techniques varies from handwritten notes to complete computer printouts of evaluated data. The eventual outputs are verification of task time data.

Use/Validity: Most HE test and evaluation efforts will require the use of one of the following (but previously indicated) event recording techniques or some variation thereof:

a) Event recorder and separate control box
b) Combined function solid state memory data collector (DATAMYTE).
c) Stopwatch.

When critical test events must be recorded and evaluated, these techniques prove valuable for determining system/operator time performance capabilities. Two of these techniques allow several task functions to be recorded at once. The observer may thereby direct more of his attention to the other aspects of the test. The stopwatch is, of course, by far the cheapest method of the three of recording time. It may, upon occasion, be the most cost effective. It is, however, more error prone than the other methods. The recordings made from the other two techniques can be used for timeline, task loading and time sharing analysis.

The disadvantages of the first two techniques, when compared to the stopwatch, are: the cost, requirement for a test with several different task function channels occurring simultaneously to be useful, and ease of use. Technique "b" is better than "a" in that it is easily portable, immediately compatible with existing computer programs, and includes an earphone timer tone.

In general, all techniques will measure objectively human performance and provide useful data for the test as a whole. The techniques can be used with very little test interference. The training required to use the technique equipment varies with the equipment complexity but is generally uncomplicated. The data are applicable for time to accomplish tasks, evaluation and optimization of tasks involving team work, and the isolation of specific points that degrade turn-around times, loading times and launch times. The technique may not be used for evaluation per se, but further analysis must be made of the data using other techniques. Additional information on the use of event recorders may be found in Reference 58 (Crites, 1969).

3.9.6.16 Secondary Task Monitoring

Description: For the purpose of determining crew workload, test participants are given both operational tasks and secondary tasks to perform. The secondary tasks may or may not be meaningless in relation to the rest of the test set up. They are, however, in no way necessary to the operational tasks being tested. The secondary tasks are performed with prototype hardware or hot mockups on special equipment that is instrumented through hardwire or telemetry to record crew performance.

Procedure: The participant is instructed to perform the secondary tasks when not required to perform the operational tasks. The time taken to perform the secondary tasks is recorded and subtracted from the total time available. In this manner, the crew workload required to perform the operational tasks is implied on the basis of the measured time (or effort) not spent doing those same operational tasks.

Use/Validity: This is a useful technique to measure crew workload particularly when it is not feasible to monitor directly the operational performance parameters. Because workload can be quantitatively measured in this case, it can be more accurate than many other workload evaluation techniques. The cost and effort to implement this technique is relatively high as compared to several other HE T&E techniques if the secondary task data are recorded automatically. However, the cost is inherently lower than monitoring operator performance on each of the operational controls (and, if possible, displays).

There are two basically different types of secondary task monitoring. The first type uses secondary tasks that are completely unrelated to the system operational tasks. These are make-work tasks. The second type is more sophisticated in that the secondary tasks are essentially the same as the required operational tasks. Test participants seem to have more motivation to do the more real secondary tasks rather than the make-work tasks. Reference 59 (Rolfe, 1971) provides more information on use of secondary task monitoring.

3.9.6.17 Physiological Instrumentation

Description: The process of measuring test participant physiological data is generally quite rigorous. In addition to all of the set up procedures required for the test itself, it requires several important tasks that must be performed just for the physiological instrumentation.

Physiological measurement requires more commitmment from the test participants. The purpose of the instrumentation may be to monitor physiological parameters to insure that the participant remains in a safe range of performance. The implication of this is that there is a possible unsafe range of performance and therefore more commitment required on the part of the test participant. Even if this is not the case, the encumbrances of the test sensors on the participant are generally somewhat annoying.

Procedure: Trained medical personnel must approve the test. Generally, they should perform the test set up of the instrumentation system. This would involve the attachment of the sensors in a manner to minimize their effect on the total test. Medical personnel must also be present during the test if any participant risk is involved. Electronics technicians may also be required to adjust the test instruments.

In addition to the individual parameter sensors located on the participant, wire leads must be provided. Attached to the leads would be the appropriate transmitters (if telemetered), receivers and/or amplifiers. Instruments for displaying parameter values and chart recorders will also be required.

Parameters that might be monitored are as follows:

a) heart rate, blood pressure
b) respiration rate, volume
c) galvanic skin response (GSR)
d) electroencephalograph (EEG)
e) electocardiograph (EKG)
f) body temperature
g) body movement.

Upon completion of the test, medical personnel are required for analysis and evaluation of the resulting test physiological data.

Use/Validity: Physiological measurement is performed much more for research testing than for operational or field type testing. It is also used when there is a possibility of risk involved, for example, centrifuge runs. Physiological testing is seldom intended to measure total system performance, let alone the more normally monitored operator performance parameters of time and errors.

The cost to perform this type of testing is relatively high and the effort involved by HFE, medical and technical personnel is considerable. Because of the nature of the test itself, which would require the use of physiological instrumentation for safety, the testing must be considered to be performed on an interference basis. When physiological monitoring is really needed, there is no substitute technique that may be used to obtain the necessary data. The only alternative of constantly stopping the test to take time out for the required measurements is unacceptable. By use of radio transmitters, the technique may be monitored remotely away from the test area. The most notable use of this technique has been in manned space programs, i.e., Skylab, Apollo, Gemini and Mercury. Reference 60 (Zonjer, 1971) provides more data on the subject of physiological instrumentation.

3.9.6.18 Physical Measurement

Description: This technique is the process of measuring what the test participants can do in terms of their physical performance or what they are doing in terms of physical and cognitive performance. Three different types of physical measurement are presented in this section. The first, anthropometry, deals with potential test participant physical performance. The other two, oculometry and voice monitoring, pertain to measurement of the participants' physical and cognitive processes.

Anthropometry. Anthropometric measurements may be made of each of the test subjects to be used in a hardware prototype or mockup test. These measurements are taken on the assumption that the test will indicate various areas of work space or work access verification. If problems are indicated, rather than designs verified, then detailed measurements are taken as to exactly how much of a work space problem exists. If much of the test is to hinge on the ability of the test participants to fit the equipment (e.g., cockpit egress), the subjects may be specially screened and chosen to fit the worst case (larger) population percentiles (95th or 98th percentile). If a subject with 98th percentile buttock-knee length the 98th percentile shoulder breadth can successfully egress with the given cockpit dimensions, then it may be assumed that most pilots will be able to do the same at least in terms of egress space.

Oculometry. This is the technique of measuring the test participant's eye movement while he is seated at (in) a mockup or prototype hardware of the system being tested. The oculometer is used to view the participant's eye movement in terms of deflection rate and amount. The instrument and associated equipment is capable of recording the links between controls and displays, the dwell times on each, the

total number of eye contacts, and the probability of next contact. The oculometer performance is at a half degree at 30 inches from the eye within an envelope 30° up, 10° down, and 60° horizontal. Once these data are recorded, panel layout adequacy is verified by the quantity, location and rate of eye movements.

Voice Monitoring. This technique is performed as a means of psychological stress evaluation. By the use of sophisticated voice monitoring equipment, similar to that being used for lie detection, the voice is analyzed to determine stress. The stress indicates test situations where the participant is having problems or is close to the point of having problems. The voice stress analysis equipment requires operation by trained evaluators. These evaluators should be familiar with the system test objectives in order to be better able to analyze test data and to recommend problem solutions.

Physical measurements may also include participant muscular strength, body weight, limb coordination, visual and auditory acuity, and kinesthetic response.

Use/Validity: Anthropometry: It is relatively easy to measure test participants to determine their anthropometric measurements. The fact that these subjects either did or did not fit the particular mockup or prototype is also easy to note and record. The difficulty in the use of this technique is if and when particular anthropometric dimensions are required as test subjects. It is very difficult for HE observers to go out and find particular anthropometric dimensional subjects, particularly for combinations of measurements and for the extremes of the population (e.g., greater than 90th percentile and less than 10th percentile).

The real value in using anthropometric measurements is in the knowledge of how close the design, as represented by the mockup or prototype, comes to the specified user anthropometry. The disadvantage is the effort in finding subjects who properly represent the required population. If this technique is not used and work space clearances are critical to the test conduct, the HE observer runs a high risk in only guessing the ant ometric characteristics of the test participants.

Oculometry. The oculometer technique is relatively complex and expensive to use. It cannot be run on a noninterference basis. It requires trained HFE observers to use. The use of the technique is still somewhat experimental. The major advantage in the use of the technique is that it is the ideal way to perform or verify cockpit or console panel link analysis data. If not used, questionaires or interviews may be used to determine subject reaction to panel layout adequacy.

Voice Monitoring. The use of voice monitoring is both experimental and controversial. Like the oculometer, it is a complex technique. It requires trained evaluators and special equipment and is therefore expensive. Interpretation of the test participant voice qualities is variable. On the plus side, the technique may reveal problems that no other technique could uncover. The only alternatives to its use are interviews and questionnaires to try and dig out stressful test situations. This technique has been used in pilot evaluation during aircraft carrier night landings.

3.9.6.19 Online Interactive Simulation

Description: Previous HFE T&E technique paragraphs have described techniques which rely heavily on prototype hardware or mockups. Also included in this guide are several techniques which do not use either mockups or hardware, but are instead computer program simulations of both the operator and equipment in the man-machine interface (e.g., CGE, CAR, CAPE). The general technique described in this section pertains to the use of real time computer program simulations and actual test participant operators. Like other simulations, online interactive programs are used to evaluate and demonstrate the application of specific procedures and equipment to specific operations. It is often difficult to make a sharp distinction between some computer simulation set-ups and functional mockups. The emphasis in the functional mockup is on an accurate representation of spatial dimensions and arrangements.

The most important requirement of an online interactive simulation is that it be an accurate representation of some portion of the proposed system. Critical variables in the proposed system should be properly duplicated in the simulation. In some cases, simulators must actually provide deliberate distortions of certain parameters in order to yield operator responses that will be valid for the real world. The use of distortions is risky but often necessary to compensate for some parameter that cannot be provided for properly.

Online interactive simulation presumes the use of a sophisticated computer and software. Test participant consoles must also be provided in a manner similar to the system consoles being simulated. The preparation of test

participant operator procedures is a first step toward the complex job of constructing the real time interactive software. Online operation requires the construction of numerous operator commands in response to numerous displays and display formats. Operator and system performance outputs must also be provided for in terms of lists and time plots of events versus actions, errors, and reaction times.

Use/Validity: The reason for using online simulation is because of the ability to find out what might occur: to manipulate, to study, and to measure the model instead of the real world.

There are several advantages to using online simulation as compared to other methods of T&E:

a) Simulators are frequently cheaper, faster and easier to construct than the systems or prototype hardware they simulate.

b) Simulators can be instrumented to collect data that would be difficult or impossible to obtain from real systems and the data may be quickly reduced to usable form.

c) Simulators are extremely useful as training aids.

d) Simulators are easier to manipulate than the systems they represent.

e) Simulators may be used to perform tasks that would otherwise be hazardous to the test participants (e.g., crashlandings).

f) Once the simulation program has been provided, alternative procedures or tactics may be easily manipulated.

g) A record of data may be kept for later playback.

The disadvantages in the use of online simulation as compared with other T&E techniques are as follows:

a) Simulation tends to invite overgeneralization.

b) Simulations may be wrong because of incorrect relationships that have been made to hold between variables, or assumed constraints may be in error.

c) Simulators may add ingredients of their own that will not be found in the real world system.

d) Simulators, in general, are very expensive.

The time to use online simulation is generally before the construction of the hardware (and software) that it is to simulate. If this is not done, there is little point in the expenditure of the time and effort for the simulation.

There are essentially two alternatives to the use of online interactive simulation. One simulation technique is the use of man model programs such as the CGE, CAR and CAPE models previously mentioned. The other alternative is the use of all the T&E techniques which utilize the direct or indirect data obtained from the actual prototype system hardware.

3.9.6.20 Statistical Analysis

Description: This section on statistical analysis techniques is applicable to both system analysis and evaluation. In order to maintain consistency between this section and other HE techniques sections, the details of the numerous statistical methods cannot possibly be provided herein. However, a few of the more commonly used techniques are briefly presented along with their use. These techniques have been grossly categorized into the two areas of: a) statistical comparisons, and b) user population selection.

Statistical comparisons may deal with the parametric performance of two or more hardware items under consideration for use in the system design. Comparisons may also be made between different parameters in order to draw a conclusion or develop new and useful data. System trade studies often include performance data comparisons such as reliability statistics. The mean or average reliability for one hardware item being considered is compared to another hardware item. Additional factors such as standard deviations from the mean and item population are necessary to make a proper performance comparison. The confidence limit or level of the results of the statistical analysis are very important. These are obtained from the standard errors which are, in turn, a measure of the sampling uncertainty (e.g., sample size). Statistically derived data are of little value without an associated confidence limit (e.g., 95%).

User population selection deals with the selection of a sample from total population. It is generally impossible to test or measure all items (or users) in a population set from which data is to be obtained and analyzed. Statistical methods exist for random or specific parameter (i.e., stratified) population sampling. Whether a total population or a sample of the population, the data obtained will be presented in distribution plots. These plots describe the frequency of occurrence of the individual parameter values in the sample tested. The form of the resulting distribution (e.g., Gaussian, Poisson, binomial) is important in selecting the appropriate statistical techniques to be employed and in the conclusions to be drawn from the data. For example, a bimodal distribution generally indicates that the data sample was actually drawn from two distinct populations and the

application of standard statistical techniques may not produce the intended results. As a further illustration, recent trends in design criteria application require the combination of male and female population anthropometric data. This combination will produce bimodal distributions. In such situations, standard statistical techniques for determining cost effective design criteria (e.g., choice of 5th through 95th percentile) can be erroneous.

Procedure: It is not the intent of this guide to provide the procedure for each of the many statistical analysis techniques. If the HE specialist has questions concerning data analysis and interpretation, consultation with a statistical specialist should be employed. This consultation should occur during the early planning stages. Errors in sample selection or data collection procedures cannot be corrected in the analysis. Statistical analysis that once was performed with the use of desk top mechanical calculators is now quickly performed by computer/software techniques. If possible, statistical data should be collected in machine-readable form at the test site. At a minimum, the data collection format should be designed for ready use as a guide for key punching of input cards.

Use/Validity Although HE itself is a specialized field, there are persons within this discipline who specialize in HE statistical analysis. The majority of HE personnel have little to do with the statistical analysis, both because of relatively little need to do so and availability of a few well qualified persons who can perform the statistical analysis when needed.

Comparisons or correlation between parametric data are useful to extrapolate from limited data bases. For example, if based on comparisons between evaluator's judgments of operator task reliability and actual empirical data, a high correlation seems to be evidenced, then this correlation can be quantified by the use of scatter diagram plots, regression curves, and correlation coefficients. The quantified correlation can be used, with some caution, to extrapolate to operator task reliability estimates which have not been field tested. Correlation data showing the relationship between anthropometric measurements can also be very useful.

Statistical methods are not used as often as they should be to evaluate parametric data used to perform trade studies. Often hardware selection between various brands and systems is made on the basis of quoted or derived performance data that is not statistically reliable (significant) or accurate.

Just as statistics can be of great value to the HE analysis and evaluation process, it can also cause problems. If the statistical analysis is attempted by persons with limited experience, it is easy to make mistakes both in the choice of particular statistical techniques and in the application of the techniques. At the same time, skilled but unscrupulous analysts have been known to purposely misuse statistics to "prove" an item of performance data which does not actually hold true. A thorough analysis should be made of any data which are crucial to a design decision and which could be suspect.

3.9.7 Data File

The contractor HE organization shall establish and maintain all HFE and HE related data generated on the program in the HE Data File. These data, such as the HE plan, analyses, design review results, drawings, checklists, and other supporting background documents reflecting HE actions and decision rationale, shall be maintained and made available to the procuring activity at the contractor's facility. Typically, these data will be reviewed at various contractor meetings such as design reviews, audits, demonstrations, and T&E functions. The data file shall be organized to provide traceability from the initial identification of HE requirements during analysis and/or system engineering through design and development to the verification of these requirements during test and evaluation of the approved design, software and procedures.

3.9.8 Baseline Monitoring

A method frequently used by program management to keep both the program moving and the design improving at the same time is the establishment of a baseline configuration. The design is controlled by drawings and documents describing the total system. The initial configuration is established by the program manager with the assistance of the chief engineer and others. Prior to the program CDR informed contractor meetings are called to review changes to the baseline. After CDR a more formal change board is established to control the necessary design changes and their accompanying documentation. After the CDR, the baseline is bought-off by the customer and design changes must be approved and paid for by the Air Force (by way of Engineering Change Proposals: ECP's).

A typical baseline configuration might start out during the conceptual phase as a description of the system in terms of required system performance and design requirements. This will eventually evolve into configuration item performance and design requirements by the end of the advanced development (validation) phase. Configuration item product definition must be maintained through the full-scale development and production phases.

The baseline system design provides a single source for all program groups to quickly reference. This is most necessary in order to make quick and accurate trade studies to determine significance of cost and performance trade-offs. The baseline configuration provides a model which can be used for planning and scheduling purposes. It is imperative that manufacturing and engineering are using the same system configuration. It is imperative that HE personnel monitor the baseline configuration to be sure that it includes proper consideration of the man-machine interface and necessary HE design criteria.

3.10 Contractor Monitoring

After the contract award is made, contractor monitoring can be accomplished in a number of ways. These are the HE Program Plan, conferences, design reviews, trade study reports, CDRL reports, HE data file review, baseline configuration review, and frequent use of the telephone.

If an HE program plan is required, it must be reviewed and modified if necessary within a few weeks from the start of the contract. A program kick-off meeting for just HE alone is a good idea to discuss any ambiguities in the plan and to make necessary changes. The meeting is also helpful in that the customer and contractor can meet face to face and go through the plan section by section prior to later important design reviews. The meeting should be at the contractor's facility in order that the facility itself and the work (e.g., mockups) already performed on the contract in competition can be shown to the Air Force customer. Once approved by the Air Force manager, the HE Program Plan will be the basis for the HE contractual compliance.

If progress reports are required, they must be reviewed and evaluated. The Air Force HE responsibilities in reviewing design data may vary from complete responsibility in the case of data submitted in response to MIL-H-46855 or HE CDRL items, or to just "comment" or concurrence action on other data. The scope and purpose of the review is to assure that the

contractor's efforts are of acceptable quality and in accordance with the contract specification and work statement. The Air Force HE manager must also attend major design reviews such as the PDR and CDR. He must insure that his contractor counterpart is a significant participant in the presentation of program data. The increased attention and emphasis on evaluation during early design phases have led to the frequent use of mockups to assist in design evaluations. Early development of mockups is required in the full-scale development phase and helps to serve as a design configuration aid. The Air Force HE manager may also wish to attend certain test and evaluation events which are significant to the man-machine interface. He may initiate design review unsatisfactory reports (i.e., deficiency reports). He may participate in the initiation (by other Air Force managers) of ECP's when required.

Frequently, the system design will progress by means of an evolving baseline configuration. The baseline will probably start as that indicated in Section 3.9.8, Baseline Monitoring. In order to insure that all subsystems or elements of the WBS are directed toward the same configuration, a baseline with configuration control is maintained. It is modified only with agreement of all affected and the modifications are published for information and review to those organizations that should be involved. It is part of the Air Force HE manager's job to keep track of this baseline configuration and to insure that there are no potential existing HE problems associated with the design.

During the period of design reviews (or at any convenient time), while the Air Force HE manager is visiting the contractor, the contractor's HE data file should be reviewed. This file should contain copies of correspondence, reports, analyses, specifications, sketches, drawings, checklists, and test data reflecting HE actions and decision rationale. This review time can be well spent to assess how well the contractor is doing his job.

Generally, during the period of program acquisition, the Air Force HE manager is available to answer contractor questions, provide certain Air Force data, and give advice. However, in recent years, a few program acquisition phases have been completed. Hardware has been designed and prototypes constructed for a fly-off. In this kind of a competition, it is extremely difficult for the Air Force HE manager to provide help to one contractor without being very sure that the same help or information is provided to the other contractor(s). In this situation, the total efforts of the Air Force HE manager must necessarily be much greater than if there were no competition.

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